# Multi-touch and Mobile Technologies for Galleries, Libraries, Archives and Museums

by

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# Abstract

Technological developments open new opportunities to meet the increasing expectations of visitors to galleries, libraries, archives or museums. Although these technologies provide many new possibilities, individual challenges and limitations are rife. Galleries, libraries, archives and museums should aim to unify many such technologies in order to capture visitor attention, engage interaction and facilitate both personal and social experiences. By incorporating objects, devices and people into a network of interconnected systems, new patterns, interaction types and social relations are expected to emerge.

This thesis explores the unification of these technologies, identifies behavioural patterns emerging from visitor interactions and examines how combining these technologies can contribute to engaging visitor interactions and the effects they have on both individuals and groups.

The thesis states that combining mobile devices and interactive displays will offer new engaging interactions for museum visitors. This will allow them to spread their interactions throughout the museum and easily switch between private and social experiences. Museums should therefore adopt combinations of mobile devices and interactive displays to meet the increasing expectations of their visitors and offer both private and social experiences.

Acknowledgements

After I applied for a Ph.D. position at the University of Birmingham in 2011, I had my initial interview with four academics from two different departments. Not long after the interview I was offered the position and started working as a cross-disciplinary Ph.D. researcher at the Digital Humanities Hub and the Human Computer Interaction Centre. If not for these four brilliant people, this piece of work would not exist and my life would have looked a lot different.

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# Part I

# Define

# Chapter 1
# Introduction

This thesis describes how combinations of new technologies can contribute to engaging visitor interactions and which effects these have on both individuals and groups. This work will first present a framework to combine new technologies for creating novel interaction methods for visitor engagement. These novel interaction methods are then evaluated in a study to determine user satisfaction and acceptance. Results from this study are fed into the development of new interactive exhibitions and subsequent studies evaluating the effect these have on both individuals and groups. During these studies, participants roam freely within a museum-like environment where their movement, gaze and interactions with artefacts, as well as with each other, are recorded and analysed. In line with the intended purpose of this thesis, a final study is conducted within an actual museum for comparison. The results and findings of this work will help galleries, libraries, archives, and museums (GLAMs) in creating a more engaging experience within our knowledge-based society.

## 1.1 The Age of Information

In today's Information Age technological innovations follow one another rapidly and increasingly play fundamental roles in our daily lives. Being connected is now embedded in our modern-day society and the current generation is online the moment they wake up. We use vast online resources to formulate opinions, make decisions, contribute to online discussions, share information and keep connected through social networks. Moreover, technological innovations not only shape how we socialise and interact with each other but also how we engage with our environment and the objects around us.

Accompanied by new Human-Computer Interaction (HCI) paradigms these technological innovations pervade our society and influence how institutions, both private and public, can have an impact on us, their visitors. Especially for GLAMs there is suddenly a dazzling array of new technologies to choose from that might help them to get through to the current, and next, generation of visitors. In order to meet the increasing expectations of their visitors GLAMs now look expectantly to these technological innovations trying to respond to the next big trend. Although these institutions find it hard to adapt in our knowledge-based society, no public institution can escape the inevitable transition into today's Age of Information.

## 1.2 Technological Developments and Rising Visitor Expectations

Almost simultaneously HCI research tries to understand the effects these technological innovations and new HCI paradigms have on their users. As a result, researchers have been conducting both in-lab and in-the-wild studies in GLAMs. These studies provide either a controlled environment or ways to observe how users interact with new technologies in their intended setting [69]. With many interaction opportunities, educational as well as entertaining experiences and a wide variety of users, communal spaces such as museums provide a suitable location for similar studies [47, 20]. This thesis will therefore focus on museum environments which are influenced by the introduction of new technologies as well as the rising expectations of their visitors.

Although a large part of the success of these new technologies might be due to their novelty, other important factors are high quality in design, software and functionality. As novelty is likely to wear off over time, the latter will hopefully provide sufficient attractive elements to keep them successful. As it is the content that makes an exhibit unique

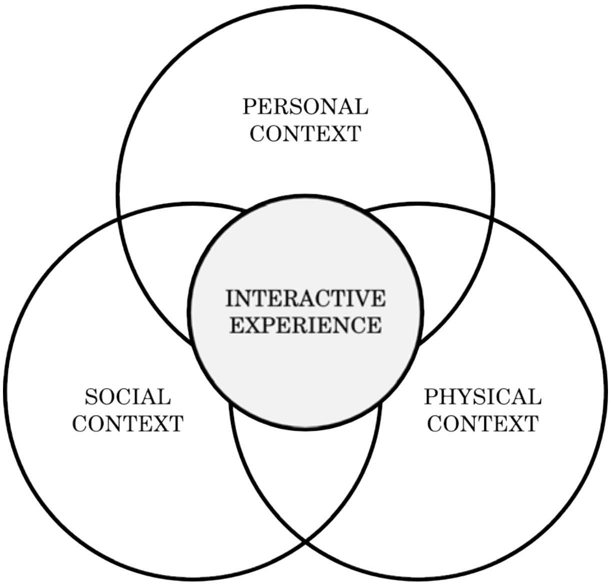
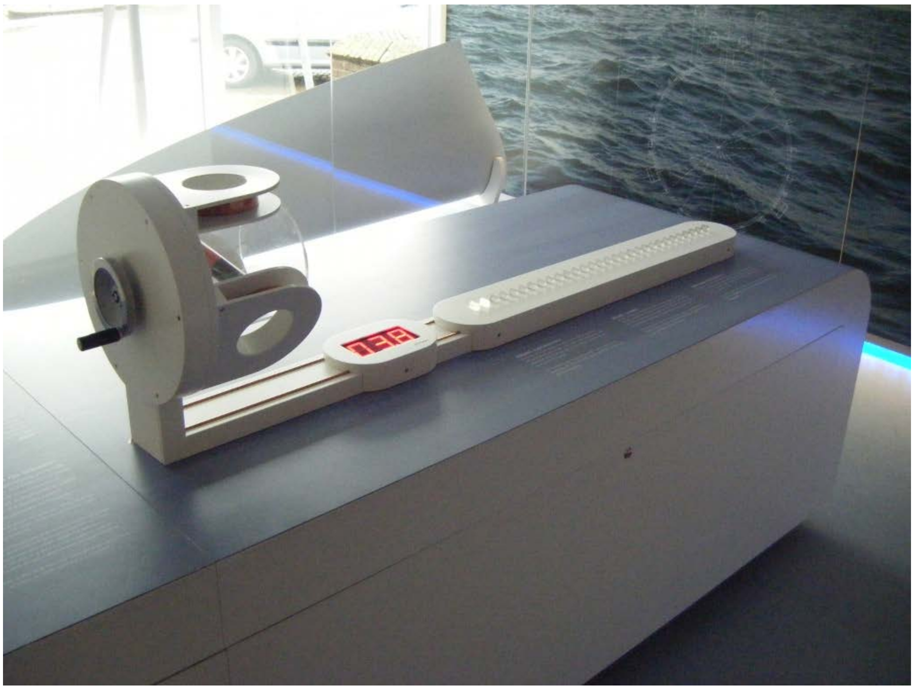



Figure 1.1: The Interactive Experience Model.

and visitors' opinions that drive museums, it is important to understand what visitors are looking for. According to Geller a visitor "wants a museum visit to remain sensual, visceral, and direct" and "by moving the orientation of the digitally interactive experience, museums are answering the call" [32]. Dierking *et al.* have tried to capture these elements into their Interactive Experience Model to define and redevelop museum experiences [24]. In this model they propose three main contexts: *1*) a personal context; *2*) a social context; and *3*) a physical context (see figure 1.1). Together the three contexts make "up the total visitor experience" [24] and is unique for each visitor.

According to Dierking *et al.* "the visitor's experience can be thought of as a continually shifting interchange between personal, physical and social contexts" [24]. And indeed, for most people a museum visit is often a social event, they visit museums in pairs or groups and exploring a museum environment can be a collaborative activity. Which exhibitions to visit, the artefacts to examine, and what people learn from their visit is often the outcome of their combined interaction [89]. Additionally, they expect their visit to be fun, social and educational, with interactive and engaging exhibits [73]. Museums should therefore aim to encourage social interaction, and encourage families, friends, and groups to explore museums together [11]. In order to meet these expectations museums are adopting new



(a)


(b)

Figure 1.2: Two examples of interactive exhibits with, (a) a model of a wind turbine to illustrate how electricity is generated at the Tourist Centre NoordzeeWind in Egmond aan Zee (Netherlands) and (b) an interactive display providing information about footprints which is part of the 'Crime Detectives' exhibit at Thinktank - Birmingham Science Museum in Birmingham (UK)

technologies and creatively apply these technologies so that visitors are engaged in a more personal and social experience (see figure 1.2). As museums visitors' time is limited, they like to fill their leisure time with new experiences, worthwhile activities, and something they can learn from. They satisfy their desire to learn, discover and understand [39]. However, according to Hornecker "it is not necessarily the installations with the most interactivity (or content) that make good and engaging exhibits" [45]. Their interaction with each other, as well as with other visitors, also determines how visitors experience the museum visit; they want to participate actively, be part of the experience and engage with the collections, as well as with each other [43]. This has led to the development of interactive exhibits which appeals to both families and the younger generations alike. Moreover, the "current technological trends are producing a wide availability of multi-device environments, characterised by the presence of both mobile and stationary devices" [25]. Although museums are trying to find new ways to use these technologies to offer engaging experiences to their visitors, "like everyone else, museums are still coming to terms with what such technology can do" [64]. Finding an answer to this problem will provide the basis for this thesis.

## 1.3 Problem Statement, Motivation and Research Questions

While technological innovations influence people throughout their every day lives, they also influence how people relax and what they expect from their leisure time activities. However, how can museums cope with these rapid changes and how can they stay on top of these innovations? Not only do museums need to keep the current visitors satisfied, they also need to address future visitors who will be looking for new engaging experiences, something they have not seen before. They want to participate actively, be part of the experience and engage not only with the collections, but also with each other.

When Sachatello-Sawyer *et al.* [73] interviewed groups of museum visitors and asked them what museums could do in order to increase visitors' experience, more than 70% indicated they wanted 'hands-on' activities. Although this would increase the visitors' experience positively, being actively engaged with experiences is also how people learn, how they make sense of the world and will eventually lead to the desire to learn more [11]. The real challenge will be to not only physically engage visitors, but also engage them mentally, or as Black [11] calls it to provide a 'mind-on' experience instead of just a 'hands-on' experience. However, as Cosley *et al.* mention, "visitors also enjoy the social aspects of museum going" [22] and therefore the social aspect of museum visits should not be overlooked.

In order to engage their visitors, museums are adopting new technologies which come with many possibilities. However, these technologies also have their individual challenges and limitations. As combining these technologies could help to overcome their limitations, museums should start looking at the unification of many such technologies. This would allow them to grab visitors' attention, actively engage them and let them be socially active. Therefore, this research aims to explore how combinations of new technologies can contribute to engaging visitor interactions and the effects they have on both individuals and groups. Formulated into the following research questions this forms the basis of this thesis.

1. How can combinations of new technologies facilitate visitor engagement and interaction in a museum environment?

2. How can combinations of new technologies facilitate social interaction in a museum environment?

3. What are the effects of combining new technologies in a museum environment on user experiences?

4. What are the effects of combining new technologies in a museum environment on group experiences?

## 1.4 Contributions of this Thesis

The aim of this work is to explore how combinations of new technologies can contribute to creating interactive and engaging museum visits while supporting both social and personal experiences. Understanding how combinations of these technologies influence visitor behaviour will benefit both the HCI and Digital Heritage domains and the outcomes of this work aim to feed into the development of future interactive museum experiences. The contributions of this thesis are as follows:

- A framework which uniquely identifies artefacts, devices and people within a museum environment and provides the means to discover, and make use of the technological capabilities of each element (chapter 3);
- Prototypes of interactive exhibitions combining mobile devices with interactive displays to support user interaction with museum artefacts and display cases (chapters 4 - 7);
- Guidelines for combining mobile devices with interactive displays. To support engaging experiences using combinations of mobile devices and interactive displays, a mobile device should be an integral part of the interaction (chapter 4);
- Guidelines for using combinations of mobile devices and interactive tabletops for museum exhibitions. Increased interaction time with an interactive tabletop resulted in a reduced interaction time with museum artefacts (chapter 5);
- Deepened understanding of groups interacting around an interactive tabletop. Socialising effects which have been attributed to interactive tabletops depend on the composition of the users interacting with them (chapter 6);
- A holistic overview of applying combinations of new technologies within a museum, from in-lab testing to in-the-wild application. The work illustrates the strengths and weaknesses of both and how close collaboration between the two can contribute to the development of engaging museum experiences (chapter 7).

## 1.5 Publications arising from this Thesis

Parts of this thesis have been published and presented during a number of conferences. This work elaborates and complements these publications. These publications are:

G. Hakvoort, (2013) The Immersive Museum. *In Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces (ITS '13).* ACM, New York, USA, pp. 463-468.

G. Hakvoort, R. Beale and E. Ch'ng (2013) Connect and Connectivity: Revealing a World of Interactions. *In CHI '13 Extended Abstracts on Human Factors in Computing Systems (CHI EA '13).* ACM, New York, USA, pp. 1647-1652.

G. Hakvoort, E. Ch'ng and R. Beale (2012) The Museum Environment: A Complex Community of Objects People and Devices. *International Journal of Heritage in the Digital Era*, EuroMED Supplement. 1(1), pp. 119-124.

In addition to the publications that have been included in this work, another publication has contributed to the formation of this thesis but is not included. This publication is:

E. Ch'ng, V. Gaffney and G. Hakvoort (2014) Stigmergy in Comparative Settlement Choice and Palaeoenvironment Simulation. *Complexity.*

## 1.6 Overview of the Thesis

This thesis is split into three parts, Define, Research and Report. The first part of this thesis, Define, starts with the introduction and is followed by an overview of relevant literature. This overview will first set the scope for this thesis, identifying new technologies used for engaging and interactive museum exhibitions and will continue with highlighting their strengths and limitations. After the literature review the methodology of this thesis proposes a new strategy where combinations of new technologies work together to overcome each others' limitations and support engaging and interactive museum experiences. In the second part of this thesis, Research, the proposed strategy is tested and evaluated to study the effects on both single users and groups of museum visitors. A number of these studies will be done in a controlled environment. Finally, in line with the intended purpose of this thesis, a final study is run in an actual museum. After the studies all results are discussed in the final part, Report. Here the thesis provides an overview of the findings and comes to its final conclusion.

# Chapter 2
# Literature Review

In order to gain a deeper understanding of which technologies are currently being applied in museum studies, their advantages and limitations, this chapter will first explore available literature. This will lead to an overview of existing issues with these technologies and potential solutions.

## 2.1 Setting the Scope

To gain insights in the breadth of available literature and set the initial scope for this thesis the number of publications related to museums were indexed. For this Thomson Reuters' Web of Science was used where publications were captured whose topic contained the word 'museum' and were published between 1980 to 2012. This resulted in the search key: Topic=(*museum*) AND Year Published=(1980-2012). The initial search yielded a total of 56.376 publications which roughly translates to 4.6 publications per day over a period of 33 years. Although this illustrates the popularity of museums as a topic for research and publication, the results also cover a broad set of research domains that fall outside the scope of this thesis. In order to narrow down the initial search results the search key was extended to only look for technological innovations for visitor engagement or interaction. The search was therefore adjusted to only include publications whose topic also included the words 'interact' or 'engage'. This led to the search key: Topic=(*museum*) AND Year Published=(1980-2012) AND Topic=(*engage* OR *interact*) which resulted in a total

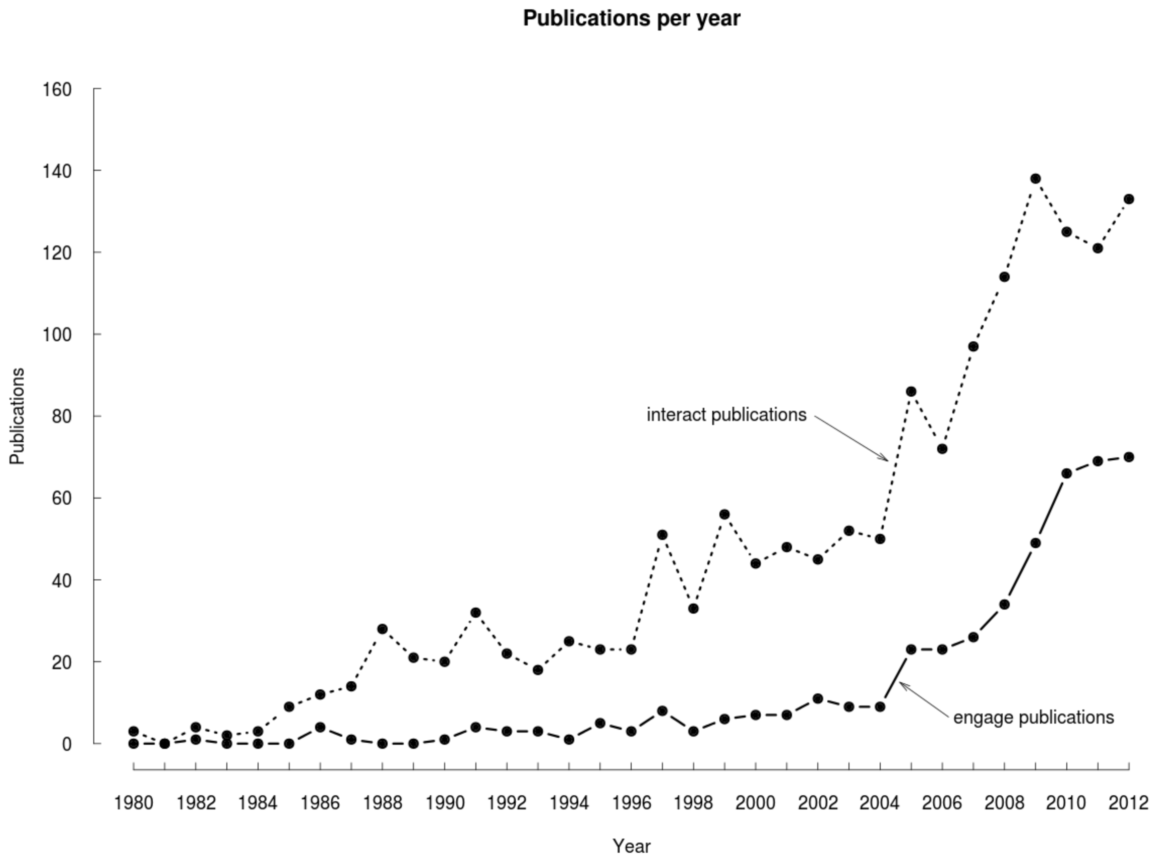



Figure 2.1: The number of publications whose topics include the words museums, and interact or engage.

of 1860 publications. Out of these 1860 publications, 1414 were related to 'interact', 336 were related to 'engage' and 110 publications were related to both 'interact' and 'engage'. Although this is only a small percentage of the initial search results, when looking at the number of publications per year there is an increase in publications for topics including 'interact' or 'engage' (see figure 2.1).

The publications found during this initial search covers a broad range of publishers from a variety of academic fields. From Elseviers' Computers & Education, to Taylor & Francis' International Journal of Science Education to Wiley's Zoo Biology. Although this provides some insights in the breadth of the available literature, further analysis of the publications is necessary to set the initial scope of this thesis. To get a better understanding of the topics covered in the indexed publications, their keywords were extracted for further


Figure 2.2: Overview of the top 100 most frequent used keywords in publications related to museum engagement or interaction. The size and colour of the keywords reflect the frequency.

analysis. Given the large number of publications this was done with an automated script for which only publications with a Digital Object Identifier (DOI) were used. The DOI provides a persistent citation for a wide range of publications and offers access to online (meta)data about the publications. Out of the initial 1860 publications related to museum engagement or interaction, keywords from 801 publications were extracted which resulted in a total of 2907 unique keywords. From these, the 100 most used keywords were further analysed (see figure 2.2).

| Keyword | $f$ | Keyword | $f$ |
|---|---|---|---|
| **museums** | 34 | **cameras** | 10 |
| **virtual reality** | 28 | **cultural differences** | 10 |
| **museum** | 22 | **visualization** | 10 |
| **art** | 20 | **human-robot interaction** | 9 |
| **internet** | 15 | **user interfaces** | 9 |
| **education** | 15 | **archaeology** | 9 |
| **exhibitions** | 14 | **augmented reality** | 9 |
| **humanities** | 13 | **application software** | 9 |
| **heritage** | 13 | **human robot interaction** | 8 |
| **history** | 12 | **mobile robots** | 8 |
| **ubiquitous computing** | 11 | **multimedia computing** | 8 |
| **interactive systems** | 11 | **humanoid robots** | 7 |
| **virtual museum** | 11 | **educational institutions** | 7 |
| **cultural heritage** | 11 | **informal learning** | 7 |
| **virtual environment** | 10 | **computer graphics** | 7 |

Table 2.1: Top 30 keywords used in publications related to museum engagement or interaction and their frequency ($f$).

### 2.1.1 Cultural Heritage and Human-Computer Interaction

The word cloud in figure 2.2 shows the 100 most frequent used keywords of the publications where size and colour of the keywords reflect their frequency. As expected, due to the initial search keys, 'museums' as well as the keyword 'museum' appear in the top three most popular keywords for the publications (respectively 34 and 22 occurrences). Furthermore, in line with the large amount of publications related to the search key 'interact', keywords such as 'interactive systems' and 'human-robot interaction' are also popular keywords for the publications (11 and 9 occurrences respectively). Additionally, the top 30 most frequent used keywords is filled with terms related to the field of HCI (see table 2.1) (e.g. 'virtual reality', 'ubiquitous computing', 'virtual environment', 'user interfaces') but also with terms from the field of cultural heritage (e.g. 'art', 'exhibitions', 'humanities', 'heritage', 'history').

Although these keywords give a good impression of the main topics within these publications, when looking at the technologies used for interaction and engagement these can be separated in two main categories. Those which try to engage visitors throughout their stay, and those which try to engage visitors with unique exhibitions and exhibits. However, as visitors come in groups, pairs but also by themselves, museums try to facilitate both social and personal experiences, each of these technologies contributing in their own way. One carried around, mobile, the other in place, stationary. In order to finalise the initial scope new keywords from the last five years related to technologies were extracted to further direct this thesis. Although breaking down the keywords any further does not leave many related publications per year however, one keyword stands out: space technology. The publications related to this keyword will be further analysed in the following section.

### 2.1.2 Space Technology

Within this research area museums try to understand "how to conceptualise and analyse the architectural organization of display spaces in museums and the movement of visitors within them" [87]. When build from, or augmented with video, audio, and computing technologies these environments are often referred to as media-spaces. In order to understand the possibilities of computing technologies within these media-spaces, researcher have been studying the impact of media-space technologies. Whilst "media space technology improves the accessibility of people to one another, some may feel that their privacy is compromised" [7]. On the other hand, Parry *et al.* suggest that "ICT is becoming integral to and innate within our notions of both the modern museum and the modern gallery" [64] and researchers do recognise the "need for didactic exhibition elements that ground the user and enable some level of engagement with the subject matter" [56] for which these technologies could be used. One of the technologies described in the publications tagged with 'space technology' are interactive displays which "offers new potential for presenting information at museums" [42]. One of the potentials of these interactive displays is, that they allow exploring information and content together with others. Although "enabling collaborative information exploration supports and recognizes of the social aspect of a museum visit" [42] these technologies "have not been as successful as audio guides in the past" [85]. One of the other technologies described in the publications tagged with 'space technology' does not have this issue, namely: mobile devices which for example can "provide location-aware information avoiding the need for users to manually select the desired information they want to see" [85]. Both of these technologies, their strengths, and their limitations, will be further analysed in the following sections.

## 2.2 Interactive Displays

As the invisibility of the technologies is an important factor for museums they have been looking for "creative interface systems to encourage interaction with computer-mediated displays, while keeping the technology in the background" [32]. The interactive display studied by Hinrichs *et al.* [42] meets both of these requirements and other museums have been adopting similar installations into their exhibitions. These interactive displays come in a variety of sizes or shapes and even their location and physical setup can have a great influence on how they will be used. Horizontally placed interactive displays, usually referred to as interactive tabletops, have a greater interactive area compared to vertically placed interactive displays as they are less restricted to the limits of the user's body [32]. In addition, interactive tabletops "encourage a homier, more-familiar, collaborative atmosphere" [32] and appeal to aspects of users' daily lives, such as using horizontal surfaces as a workspace and using gestures to manipulate and interact with information. However, according to Ryall *et al.* "orientation of information on interactive tabletops is more complex than on traditional, vertical displays" [71] as users can only view these vertically placed interactive displays, or interactive walls, from one direction.

In a study by Morrison *et al.* [60] an interactive wall was placed in the centre of a city and showed pictures from an online source. The pictures were presented on a large vertically mounted display with which passers-by could interact. The work of Morrison *et al.* shows that potential users were often reluctant to use the interactive wall. However, once potential users observed others using the interactive wall, they proceeded to interact as well. Heath *et al.* [38] suggest that interactive displays let users observe each others (inter)actions and thereby support collaborative group interaction. Similar findings have been found in other studies for example by Lehn *et al.* [89], Brignull *et al.* [17] or Ryall *et al.* [71]. Also museums came to similar findings when trying to get visitors to engage with interactive exhibits. According to Stewart-Young [82] one of the issues is that museum visitors feel unwelcome and embarrassed if they do not know what to do and before they can become involved with the museum exhibition visitors will need to overcome these barriers. Although interactive displays could potentially help visitors to overcome these barriers, they are publicly available and their interface is accessible to everyone. Visitors might appreciate more privacy or personal addressed information.

Geller surveyed a number of interactive tabletops at museum exhibits and found that these large interactive tabletops were often designed to be used by multiple visitors [32]. Although this might encourage visitors to use the interactive tabletop simultaneously, when interacting with interactive tabletops Ryall *et al.* found that some groups "complained that this design made them self-conscious about the possibility of physical contact with other group members" [71]. Although Ryall *et al.* suggest this might depend on the composition of a group, interactive tabletops that are publicly accessible attract a diverse user group. These groups ranged from individuals to groups of family or friends, and here the possibility of physical contact is ever present. A more guided simultaneous interactive tabletop interaction was studied by Marshall *et al.* [57] who looked at how groups of visitors to a tourist centre approached and interacted with an interactive tabletop. They designed their interface to be used by a group simultaneously. However, only in rare occasions a group actually started and ended using the interactive tabletop simultaneously. They described the use of a public interactive tabletop to resemble a 'buffet table' instead of a 'dining table'. This would suggest that users should be able to engage with the content on an interactive tabletop individually. Moreover, Brignull *et al.* suggest that "the interactive display should fit in and be able to be integrated with the other artefacts used in the space" [16]. In addition, they also suggest that users should be able to engage with these technologies "without becoming self-conscious" [17] in order for them to enjoy their interaction with a large interactive display.

In a study by Hinrichs *et al.* they found that people usually visit exhibitions in groups and that their experiences with an interactive tabletop is also greatly shaped by their interaction with other visitors [41]. In addition, the length and means of interaction with an interactive tabletop also depended on visitor's age as children engaged slightly longer with an interactive tabletop compared to adults. However, children's interaction often consisted of playful activities (e.g. tossing or gathering media on the interactive tabletop). Morrison *et al.* came to a similar conclusion with their public available interactive wall and noted that users were sometimes more interested in exploring the interface than actually interacting with it. Due to these diverse groups of users, often interacting only for a short duration [42, 41, 44], designing interfaces for these interactive tabletops is a challenge [41]. Block *et al.* [12] developed a museum exhibit using an iterative development process. Throughout the development process the exhibit was used by visitors and changes were made, or new features were added, according to visitors' responses. Davis *et al.* state that "a key design challenge is to provide visitors with the means to explore a vast information space" [23]. In their study they observed how children explored an interactive tabletop together. They found that "children negotiate their exploration of the exhibit in a variety of ways" and that "these negotiations impact the ways children make meaning from the exhibit content and their interactions with one another" [23]. Although the gestures used to interact with these interactive tabletops encourage social encounters, gestures on interactive tabletops are not only influenced by the users' preferences but also by the interaction and social context they occur in [41]. Although museums have been looking at the collaborative use of these interactive tabletops, this is something which has been studied by the research area of Computer Supported Cooperative Work (CSCW). In order to gain some understanding of how people interact around interactive displays this research area will be further explored.

### 2.2.1 Interactive Displays for Computer Supported Cooperative Work

As interactive displays offer unique opportunities for people to cooperate closely and work together on the same surface, the area of Computer Supported Cooperative Work (CSCW) has been studying how people coordinate, collaborate, share information and socialise with each other around interactive displays.

Schöning *et al.* [74] raised a lot of questions on the current development of interactive displays such as, what the benefits are of multi-touch systems compared to single touch systems, what type of applications are suitable for systems that support multi-touch or maybe even multi-user and whether there are more types of interaction gestures besides rotate, scale, zoom, point and move. In many cases, although multi-touch is supported, users often only use their non-dominant hand as support (e.g. holding the object in place) and their dominant hand to perform the actual operations [74, 41]. Moreover, as interactive displays easily scale in size, the number of simultaneous users also increase. As users might have different roles or access to restricted functions, user identification for interactive displays becomes important. However, according to Rofouei *et al.* "determining who is interacting with a multi-user interactive touch display is challenging" [68]. In order to overcome this challenge both Schöning *et al.* [75] and Rofouei *et al.* [68] combined mobile devices with interactive displays for user identification.

How pairs collaborated while using an interactive tabletop has been studied by Tse *et al.* [86]. In their study participants had to complete several tasks using a multi-modal single user application which supported both touch and speech input. Previous studies have already shown that when people interact with physical artefacts they use combinations of gestures and speech to support others joining or assisting in the activity. Tse found that this also holds when pairs interact with a digital system. People were more involved with each others actions and were able to interpret and act upon each others intentions.

However, when groups become larger there appears to be a difference. The impact of group size, as well as table size, has been studied by Ryall *et al.* [70]. In their study participants had to collaborate in order to reach a single goal. Participants had to carry out both individual and collaborative tasks often found in interactive tabletop applications such as searching, manipulating and coordinating. At the same time they also had to manage their personal and shared resources. The study showed that task completion time was not influenced by the size of the table, but was influenced by the size of the group. Different group sizes often resulted in different types of resource management and work strategies. For larger groups Ryall *et al.* even suggest to use vertical displays to present shared information and resource management. This is also supported by similar findings from Kruger *et al.* [50] who found that orientation was important for users to collaborate in terms of comprehension, communication and coordination.

Both Tse and Ryall acknowledge that a certain amount of private space is needed for users and this territorial behaviour has been studied by Scott *et al.* [77]. Although their study focuses on traditional tabletops, it still provides valuable input which can be utilised for interactive tabletops. Based on a user study they defined three types of territories which helped users to organise their actions while collaborating at a shared workspace, a personal space, a group space and a storage space. The personal space reflects the private space acknowledged by Tse and Ryall and was directly related to the users position around the table. The personal space was used for personal tasks or individual activities from which results could feed back into the group. When working in a group the centre of the tabletop was dedicated for the main activity. Additionally, users dedicated some space on the tabletop to temporarily store objects, usually near their personal space or the groups space so other users had easy access to them.

Users often try to use as much space as possible yet social protocol requires them to adapt in order to let others access the tabletop and share the workspace [77]. Since interactive tabletops in museums are available to the greater public, not all research related to CSCW will be relevant. However, some social protocols might apply to public interactive tabletops which is why Morris *et al.* [59] suggest relying on social protocols in order to solve conflicts for interactive tabletops within museums. On the other hand, Morris also found that people occasionally violated social norms when working on an interactive tabletop even though social norms suggest that some of these actions can be seen as rude. This indicates that existing social protocols are not adequate in order to prevent or resolve conflicts on interactive tabletops and further studies are needed.

### 2.2.2 Interactive Displays for Information Visualisation

Another research area which has been looking at interactive displays is the area of information visualisation. Since this research area mainly focuses on the representation of abstract data using digital means, interactivity is not one of the first things which comes to mind. However, according to Block *et al.* museums have a "long history of designing exhibits that offer their visitors unique opportunities" [12]. Moreover, Block states that "information visualisation can play an important role and is becoming more commonplace in these museums" [12]. Therefore, there are important lessons to learn from this area.

While large screens are becoming cheaper they are more often used for ambient information visualisation. However, these displays are situated in the user environment and should therefore not interfere with, or distract from, daily activities. In a study by Skog *et al.* [80] they tried to present everyday information in an aesthetic way. According to Skog, ambient information visualisation should not contain many animations as the human eye is drawn to moving images. However, when designing for an interactive display, intended for human interaction (e.g. in museums), the opposite is true and these findings could be used to draw people to the display. Not only is the human eye drawn to moving images, movement also provides information about form and functionality, it helps humans to identify objects [78]. Block *et al.* utilised this concept in order to "attract attention, support object consistency, and be emotionally engaging" [12]. In their study they found that "the particular style and rendering of the visual design and aesthetics have a strong impact on the viewer's perception of the underlying scientific concepts" [12]. This also illustrates that careful use of information visualisation can impact user's understanding of presented concepts.

Vogel *et al.* [88] used this to develop a framework for interactive public ambient displays. They describe four phases based on the user's proximity to the display; ambient display, implicit interaction, subtle interaction and personal interaction. The ambient display phase should give the user a quick impression of the overall information, similar to Skog's work. During the next phase, the implicit interaction phase, additional information can be shown in order to draw the user to an interactive display. Once the user has approached the display, personal, non-sensitive information could be presented during the subtle interaction phase. For longer user interaction, also allowing sensitive user information, the system supports the personal interaction phase. In a study by Annett *et al.* [2] they were able to determine the users' relative position to an interactive tabletop using multiple arrays of infra-red sensors. According to Annett *et al.* it is important to let users know an interactive tabletop recognises the users' presence and actions. Vogel *et al.* [88] made a similar statement, as they state it is important to inform users that a display is (inter)active. This is of course only possible when the interactive tabletop has additional sensors to detect users' positions. When users approached the interactive tabletop, a glowing orb started to follow them. The system described by Annett *et al.* [2] also allows ignoring touch input from bystanders as users need to be logged in first. When users seemed to hesitate a help menu was shown, similar to a study by Vogel *et al.* [88].

According to Vogel's work the transitions between the phases should be seamless and occur smoothly. To initialise transitions between phases they propose to utilise body movement, location or orientation (e.g. transitioning from personal interaction to ambient display when a user turns away from the display). Additionally, Vogel identified eight design principles for interactive public ambient displays. Not all of these design principles are applicable to interactive displays in museums, but they do provide a valuable guideline for future installations.

1. Calm Aesthetics: The interface should respond to, and inform users of state changes in a subtle way.
2. Comprehension: Information to the user must be comprehensible or at least easily

understandable by subtle interactions.

3. Notification: The interface should utilise body movement, location and orientation in order to determine whether to communicate with passers-by.
4. Short-Duration Fluid Interaction: The interface should be designed for short duration activities.
5. Immediate Usability: Using the interface should be intuitive, however exploratory learning techniques can be applied similar to learning from others.
6. Shared Use: Multiple users should be able to share the interface both individually or collaboratively.
7. Combining Public and Personal Information: Show non-sensitive personal information when appropriate.
8. Privacy: Users should be able to indicate whether they want specific information to be private.

Defining interaction areas based on proximity is not something new, in previous studies Streitz *et al.* [83] already defined three 'Zones of Interaction' (i.e. ambient, notification and interaction) and Brignull *et al.* [17] defined three similar 'Activity Spaces' (i.e. peripheral awareness, focal awareness and direction interaction) which roughly matches Streitz's 'Zones of Interaction'. However, Vogel has taken it a step forward by introducing a fourth area, thereby supporting both public and private user interaction once users have approached the display. Going one step further would mean to take Vogel's design principles and incorporating mobile devices into the system and offer new engaging experiences.

## 2.3 Mobile Devices

Somewhat unseen mobile devices entered society and have changed it in ways many people would not dwell upon (see figure 2.3). According to Ballagas *et al.* mobile devices could even become the gateway to interact with ubiquitous computing applications [5]. Using mobile devices to interact with interactive displays is therefore a promising application area. Mobile devices offer a whole range of modalities which can be used to enhance the user experience and interaction, and allow for both access control and personal storage [37]. In addition, as mobile devices are carried by visitors themselves, these devices "have a one-to-one personal relationship with the user: the user has personal control over how to use them and the content they contain" [84]. They could also give users a greater sense of privacy and an interactive display could overcome the limited visual output capabilities of mobile devices [31]. However, setting up data connections between mobile and other devices should be made easy, fast and reliable [5]. Various studies have therefore looked into setting up data connections between these devices using for example visual cues [94, 76], touch based cues [75] or movement based cues [68].

Fleck *et al.* [30] used radio-frequency identification (RFID) to developed a nomadic computing system for a museum with lots of 'hands-on' exhibits. They wanted to provide visitors additional information depending on their location within the museum using a mobile device. However, since the museum offered many 'hands-on' experiences, the mobile device restricted the visitors in interacting with the exhibits. An important lesson for future development is that when the goal is to enhance existing visitor experiences, mobile devices should not restrict the visitor. However, by making the mobile device part of the interaction, the technology will be part of the 'hands-on' experience. The second prototype developed by Fleck only recorded visitors actions. Although this contributed to the post-visit-experience, it gave little feedback at the time of the visit.

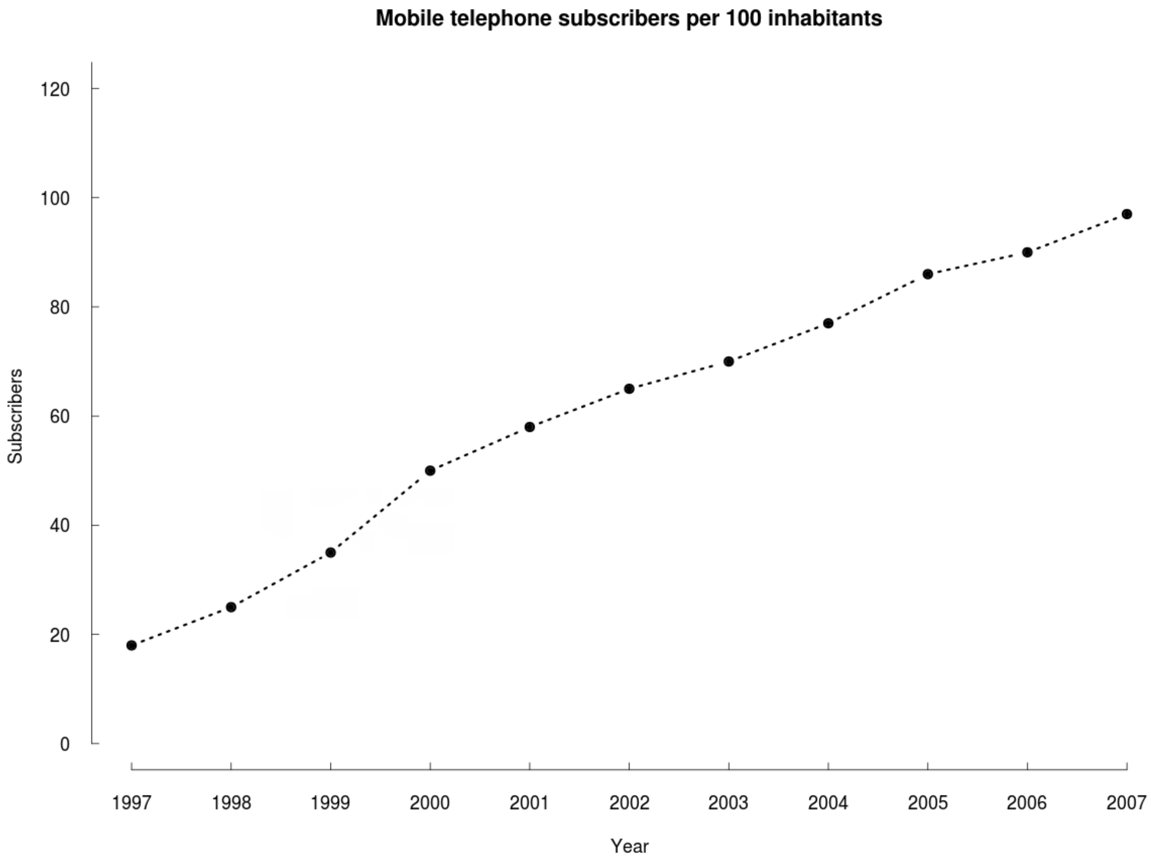



Figure 2.3: Mobile telephone subscribers in developed countries per 100 inhabitants (from 1997 to 2007).[1]

The SMARTMUSEUM project described by Kuusik *et al.* [53] aimed to give visitors to sites of interest (e.g. museums) a personalised cultural experience using a combination of existing, new and future technologies. With technologies as Global Positioning System (GPS) and RFID/near field communication (NFC) user interaction can be localised to provide user specific content [65]. Based on the users' geographical location, SMARTMUSEUM can provide user specific content on sites of interest whereas indoors, users can scan RFID/NFC tags to gain access to user specific content. This could for example be combined with the work of Haberman *et al.* who designed and developed an exhibition where RFID tags were placed behind artworks to serve as annotations and could be discovered by visitors [34]. Although a new technology, they found that "the combined

[1]Data from the International Telecommunication Union (http://www.itu.int/)

use of RFID tags and NFC-enabled mobile phones made all participants feel very quickly at ease" [34]. However, the use of mobile devices could result in less socialising situations and tend to transform a museum visits into private experiences [17] whereas museum visits are often considerate to be a group activity [41].

Aoki *et al.* also saw the potential of these mobile devices which besides "providing information to individual visitors" also had "the potential to facilitate social interaction between visitors and their companions" [3]. However, as "many systems impede visitor interaction" [3], Aoki *et al.* tried to find ways to increase visitor awareness and social experience. The aim of their study was to give "individual control over the audio content, the ability to converse and the ability to share content" [3]. For this they designed *Sotto Voce*, a system which allowed visitors to listen in into a friend's current audio stream. These streams were synchronised so the "listening friend dropped into a discussion or talk" [3]. They suggest that "when people are gathered together and involved in an activity, conversational interaction may occur, then lapse, then occur again" [3]. For example, in their study Aoki *et al.* found that visitors thought of the guidebooks as conversational participants, giving it turns and incorporating it in their conversation with their companions. In addition, the use of *Sotto Voce* also "facilitated awareness of companions" and "its use was shaped by awareness of others" [33].

In a study by Cahill *et al.* [19] the influence of mobile devices on learning and social interaction was examined. Surprisingly they found that although visitors had their heads down most of the time, it did not limit their social interaction with each other. However, as this was mainly due to the usability and novelty of the technology, the question remains how to give visitors an engaging experience while being social active.

Part of this was addressed by Kuflik *et al.* [51] who aimed to enhance the social interaction within groups of visitors. They developed a context-aware communication service which supported user-user and system-user communication. Visitors could inform each other of interesting artefacts and exhibits or leave posts-its for other visitors. The system itself could also provide additional information about an exhibit and inform visitors to view highly recommended exhibits first when they only had limited amount of time. During a user study Kuflik *et al.* [52] found that although visitors liked the user-user communication and thought it was useful, they were less motivated to actively get additional information available at the system. According to Kuflik visitors are interested in information that is presented to them but are less motivated to retrieve additional information themselves. More importantly, Kuflik notes that engaging the visitor is one of the most challenging aspects, but that combinations with interactive displays might be the next step and could engage visitors while still being socially active.

# Chapter 3
# Methodology of the Thesis

Chapter 2 gave an overview of related literature in which they apply new technologies for engaging and interactive museum exhibitions. The chapter separates the technologies into two categories, mobile and stationary, and highlights their strengths and limitations. In order to overcome these limitations this chapter addresses the first two research questions, "How can combinations of new technologies facilitate visitor engagement and interaction in a museum environment" and "How can combinations of new technologies facilitate social interaction in a museum environment?". For this the chapter proposes a new strategy where both mobile and stationary technologies work together in order to provide both social and engaging experiences.

## 3.1 Extending Interactions

One other observation that can be made from the literature review in chapter 2 is that one of the greatest challenges for museums is to make technology unobtrusive for their visitors and keep a low 'technological footprint'. In order to overcome this challenge, museums have been adopting ubiquitous computing technologies and technologies such as interactive tabletops, RFID, mobile devices and NFC in order to create interactive installations and provide hands-on experiences for their visitors. Dini *et al.* came to a similar conclusion and state that "current technological trends are producing a wide availability of multi-device environments, characterised by the presence of both mobile and stationary devices" [25].

For museums these mobile and stationary technologies could offer their visitors the new and engaging experiences they have been looking for.

For museums well designed smartphones could become a portal to interact with these ubiquitous computing applications. They offer a whole range of input and output capabilities which can be used to enhance the visitor experience and interaction. Additionally, they allow for both access control and personal storage [37] and allow private interactions [88]. Moreover, their 'technological footprint' is essentially non-existent: they get carried in by visitors, and are taken away when they leave. But maybe more importantly: visitors know how to use them. One other promising technology are multi-touch, multi-user tabletops (see chapter 2.2). These interactive tabletops come with large touch-screen displays with great computing power. Nevertheless, the mode of gestural interactions is similar to smartphone interaction styles and they appeal to aspects of users' daily lives [32]. In order to overcome the limitations highlighted in the previous chapter combining these technologies could provide an opportunity to support social interaction and engage museum visitors. For example, in combination with an interactive display the limited visual output capabilities of mobile devices could be overcome [31], whereas mobile devices could provide a more private experience while interacting with an interactive tabletop. Paek *et al.* also state that interactive displays provide "greater choice in the presentation of information, but mobile devices offer greater flexibility in the access of information" [63]. However, setting up data connections between mobile devices and other technologies should be made easy, fast and reliable [5]. Technological developments such as the Quick Response (QR) codes and wireless non-contact systems such as RFID and NFC make this a viable reality. Some museums already make clever use of these technologies by fitting their artefacts and exhibits with these technologies (e.g. [13, 21, 48, 79, 46]), making them part of larger interconnected systems, the Internet of Things (IoT).

Figure 3.1: Interacting with a painting by scanning an NFC tag; read description, comment, rate, find relations with other artefacts.

### 3.1.1 One Big Community

In the IoT [4], devices, as well as objects, people and spaces become part of a network of interconnected entities. They gain their own identity in the physical as well as the virtual environment. With a wide variety of exhibits, a multitude of artefacts and visitors bringing their own smartphones, also museums become large networks of interconnected entities. Once these entities are mirrored into a digital environment, they can then generate, manipulate, and exchange information. Visitors who wish to interact with an exhibit, the museum guiding its visitors, or artefacts conveying historical meanings; they all become part of one large community of information exchange.

While the technology remains unobtrusive, this allows localised user interaction to provide user specific content [65] and the development of novel interaction methods and new interaction systems (e.g. see figure 3.1). Also, interactive tabletops could function as interactive portals and provide, or consume, information to and from mobile devices. This

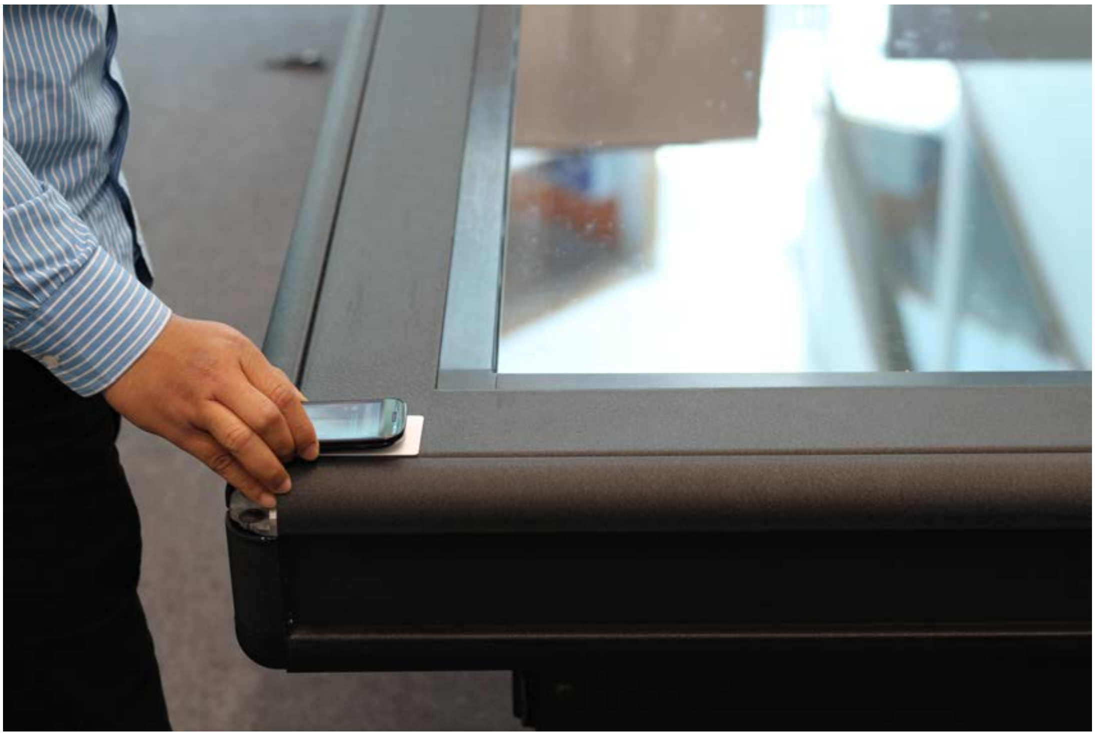


Figure 3.2: Connect with an interactive tabletop, which can then utilise the smartphone's technological capabilities.

would allow them to support both public and private user interactions (e.g. see figure 3.2).

Although the adoption of these new technologies within museums support novel interaction methods and allow for the development of engaging and interactive museum exhibits, these interactions are still bound to a place and time (i.e. they can only exist during the time span a visitor is at the exhibit). However, combinations of many such technologies can provide ways to overcome these restrictions, as it is within the connectedness of these technologies where pervading exhibits arise. Exhibits that through the unification of new technologies can present visitors with not only unique and engaging interactions but also allow them to spread the interaction throughout the museum, or even beyond. However, in order to "be able to develop and maintain a system over time so that novel components can be introduced without changing it, a flexible infrastructure is needed" [52]. In addition, these technologies should be made aware of each others capabilities in order to take full advantage of the capabilities they might have to offer.

## 3.2 Revealing a World of Interactions

The vast input and output capabilities of the entities within these interconnected networks and their combinations can open channels for novel interaction methods. In particular ubiquitous computing technologies (which are intended to become part of our daily lives) would benefit greatly from utilising each other's technological capabilities. Smartphones for example could lead visitors to a world of interconnectivity; they are personal devices that people carry everywhere, and (with a 24 hour network connection) they are already part of a large interconnected network. Provided that setting up data connections between smartphones and other entities within the large networks is easy, fast, and reliable, smartphones could become a portal to interact with ubiquitous computing systems and applications [5].

First steps have already been made by designing interactive systems in which mobile devices are connected with other technologies in order to provide new interactive modalities and creating interactive spaces [65]. This is often accomplished by specifically designing for interactions to occur and technologies to utilise (e.g. [21, 37, 67]). However, this can lead to entangled and locked-in system designs where the connectivity of the entities is deeply embedded in the design. Software design faced similar challenges and found a solution in loosely coupled designs. By communicating via flexible file formats (e.g. Extensible Markup Language (XML), JavaScript Object Notation (JSON), Protobuf), software interfaces allow elements to work with little knowledge of other available software elements. The same holds for interaction designs, as these should not be developed for the state of being connected. The aim should be loosely coupled interactive systems that support bringing together objects, people and devices in order to provide access and communication.

### 3.2.1 Opening Connectivity

The vast amount of digital input and output capabilities of technologies within large interconnected networks are hidden potentials. However, unless specifically designed for, (as for example in the work of Fleck *et al.* [30] or Kuflik *et al.* [51]), these technologies are oblivious of each others' technological features. Once objects, people and devices become part of large interconnected networks, this allows them to explore each other's technological capabilities, opening connectivity and channels for new synergy. Approaching this bottom-up will give rise to new interaction methods and interactive systems.

## 3.3 A Complex Community of Objects, People and Devices

For the studies described in chapters 4 to 7 a framework is developed that allows entities of large interconnected networks to explore, and make use of, each other's technological capabilities (see appendix A). The framework itself is called Sytizen, a combination of the Greek word **sy**nergia, meaning 'working together' and the word ci**tizen**, as being part of a community. The framework defines individual entities first and then provided the means to discover, and make use of technological properties of other entities. These aspects of the framework are separated into two parts, *a*) Identification; and *b*) Specification which will be further explained in the following sections.

### 3.3.1 Identification

In order to identify individual elements within the museum infrastructure (e.g. artefacts, exhibits, visitors), without categorising them other than by future interaction, the entire infrastructure is regarded as one single group, the Community. Within this Community each individual element is a Citizen and is defined by a Passport and a Location (see figure 3.3). Each Passport can be used to identify a Citizen and consists of a Universally

Unique Identifier (UUID), a randomly generated 128-bit value. This enables a decentralised system in order to facilitate a dynamically changing environment. To support connectivity between individual elements every Citizen can also be fitted with a Location, containing an IP address (either IPv4 or IPv6) and a port number. Once a connection is made, entities can exchange their system specification, providing an overview of information they can produce or consume.

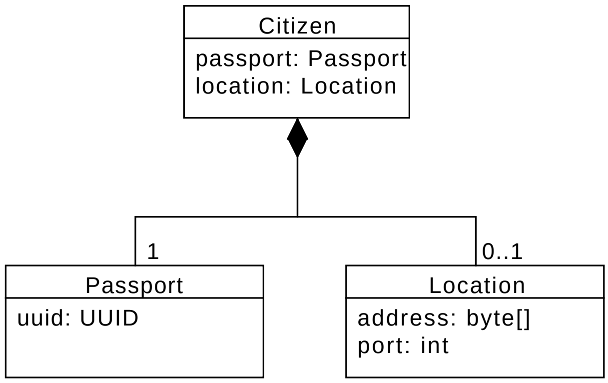



Figure 3.3: Domain model of a Citizen

### 3.3.2 Specification

To get insight in the input and output capabilities of a Citizen, the framework allows connected Citizens to discover and explore each others' specifications. A Citizen's specification is composed of a System description that represents the entire set of its capabilities described as Handlers (see figure 3.4). The Handlers are the fundamental part of a System description as they provide the actual connection to an input or output (e.g. GPS position, orientation, data storage) and describe how transmitted data is formatted.

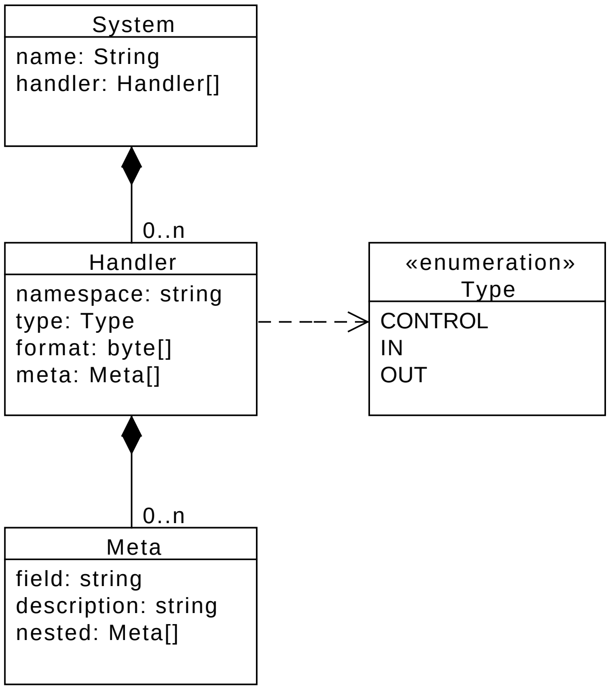



Figure 3.4: Domain model of a System description

In order to describe the flow direction of data, Handlers can be defined as an Input or Output. However, they can also be defined as Control Handlers which indicate they can be used to active and deactivate Handlers or even change their settings (e.g. data sampling rate). Two important aspects of a Handler are its namespace and format. In order to exchange data, Handlers rely on Reports (see figure 3.5) which contains a reference to the Handler's namespace. In order to make sense of the data, a Handler's format contains the description of how data is sent or how it is expected to be sent.

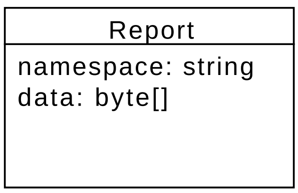



Figure 3.5: Domain model of a Report

### 3.3.3 Protocol

Both Identification and Specification descriptions, as well as the Reports containing the actual data, should be communicated according to a structured method. The final aspect of Sytizen defines its protocol - a set of rules and procedures which have to be followed when communicating. Sytizen's protocol is separated into three stages, Identification, Specification and Communication. Each individual stage handles a part of the interaction between two Citizens (see figure 3.6).

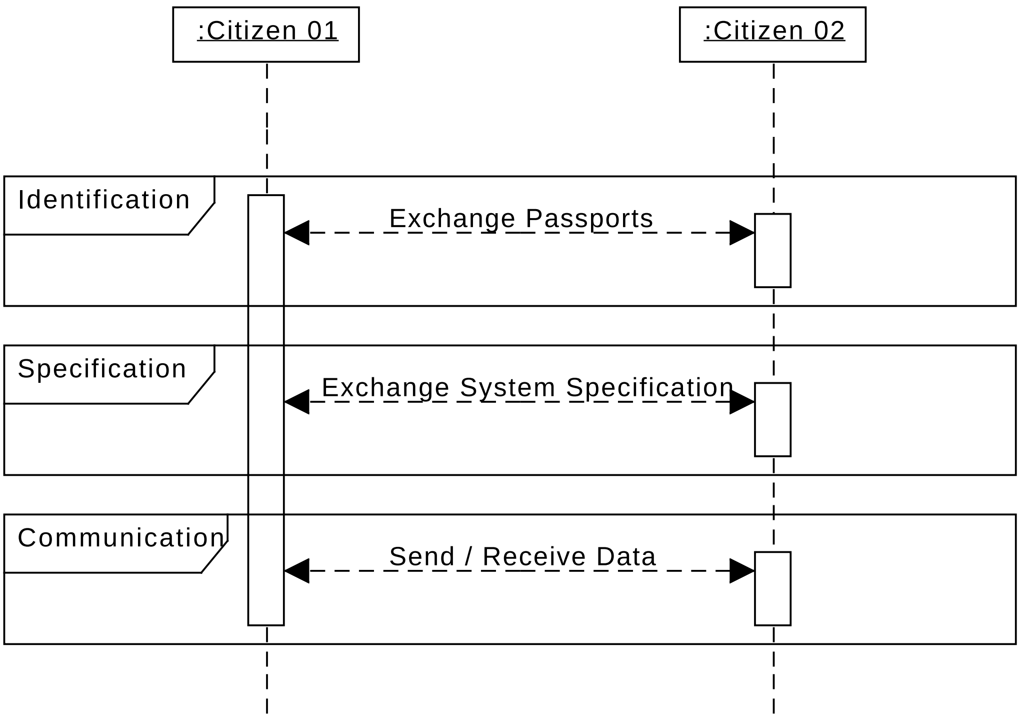



Figure 3.6: The three stages of Sytizen's protocol: Identification, Specification and Communication. Each stage has its own responsibility in order to identify other entities, provide the means to discover or make use of the technological capabilities.

When two Citizens are connected, the first step is to introduce each other by exchanging Passports. This happens in the Identification stage and allows Citizens to validate each other and could, for example, be used for access control or profile management. Additionally, this also provides the means to distinguish between different Citizens when more than one are connected. The second step takes place in the Specification stage. If a Citizen is interested in the technological capabilities of the other entity, it can request its System description. It will then be able to explore the available input and output capabilities of the other party and decide whether, and which feature to utilise. The actual data will be sent in the third and final stage, Communication. Messages for each stage are wrapped in a generic format (see figure 3.7) which allows the framework to be easily extended in the future without losing its current capabilities.

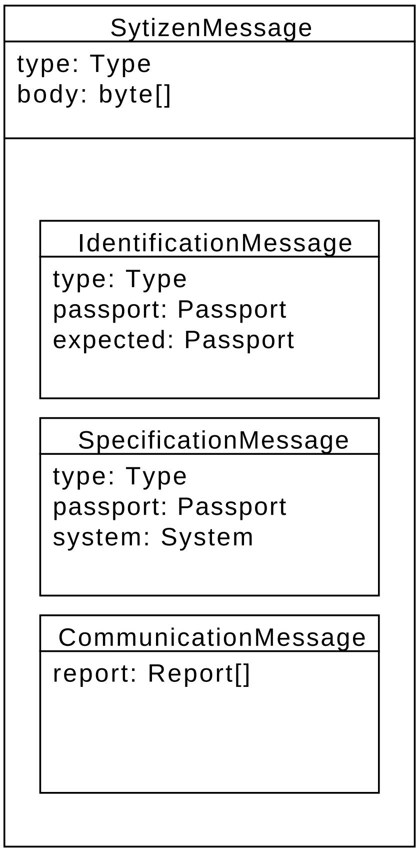



Figure 3.7: Domain model of Sytizen's generic format. Each Identification, Specification or Communication message is encapsulated in a SytizenMessage

### 3.3.4 From Virtual to Physical

NFC technology is growing in importance and seems to have increasing roles in payment transactions, transportation, and data-exchange. Smartphones with NFC capability are advantageous as they centralise user's daily activities and provide high level functions through different portals (e.g., user identification, payment transactions, social media, etc), and connection to the cellular network and services [29]. Using NFC technology as a platform for connecting objects, people and devices to large interconnected networks is simple, inexpensive and appropriate. For example, by placing NFC tags around an interactive tabletop, they "are functioning as persistent affordances for trans-surface interaction, they extend the collaborative surface display beyond its perimeter" [28] and allow interactions to be carried to, or from, the interactive tabletop.

In addition, the amount of data needed to describe a Citizen is relatively small and it can easily be stored in NFC/RFID tags or even in QR codes. (e.g. see figure 3.8). This allows any entity within a large network of interconnected entities (objects, people and devices) to be represented as a Citizen. The data needed to describe a Citizen is referred to as a Citizen Record (CR) and it provides access to a Citizen's virtual representation from the physical world. With a CR other entities can connect to the Citizen's virtual representation. Once a connection is made and identities have been verified in the Identification stage, connected entities can inspect each others' technological capabilities by requesting System descriptions and utilise available input or output channels during the Communication stage.

## 3.4 Become Connected

The Sytizen framework avoids locked-in system designs and supports bringing network entities together in order to provide access and communication. This allows entities within large networks of interconnected entities to be uniquely identified and provides the means to discover, and make use of, the technological capabilities of each entity. This would

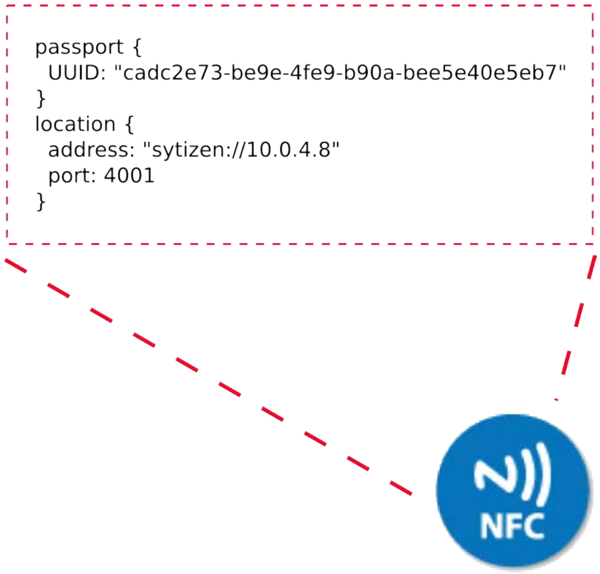



Figure 3.8: Basic Citizen information is small enough to be written into NFC tags

allow combinations of mobile and stationary technologies to be tested. However, while researchers conduct studies to try to understand the influence these technologies have on their users, some argued that the "added value of conducting usability evaluations in the field is very little" [49]. On the other hand, others suggest that in-the-wild studies "can play an important role in the design and evaluation of Ubicomp applications and user experiences" [69]. One of the main issues that lies at the heart of this debate is the trade-off between a controlled environment and an intended setting. On one hand "the lack of control in field-based evaluations makes it challenging for evaluators to conduct field evaluations in practice and to make sure that every aspects of the system is covered" [49]. Whereas, to "capture the complexities and richness of the real world in which the applications are placed" [69] is difficult for in-lab studies.

In order to overcome this trade-off between a controlled environment and intended setting, the Digital Humanities Hub at the University of Birmingham developed The Michael Chowen Prototyping Hall (see figure 3.9). Here researchers can unobtrusively observe user interaction in a museum-like environment. The Michael Chowen Prototyping Hall, or from here on referred to as 'the Hall' is equipped with:

- Two 65” multi-touch tables
- Four vertically mounted 65” multi-touch displays
- A 3m x 2m 4K 3D multi-touch wall
- Microphone and speakers
- A Vicon Tracker system to track movement of up to 40 users
- An adjacent observation room with one-way windows
- A variety of smartphones

Figure 3.9: The Michael Chowen Prototyping Hall at the University of Birmingham with two multi-touch tables, four vertically mounted multi-touch displays, a 3 by 2 meter multi-touch wall and Vicon Tracker system[1]

[1]Picture ©Daniel Graves Photography 2014

In order to study the combinations of technologies a number of studies were conducted at the Hall. Each study will contribute to answering the third and fourth research questions. The setup of these studies, and how they attempt to answer the research questions, can be found in their methodology sections in chapters 4 to 7. For these studies specific applications will be developed for the vertically mounted multi-touch displays, the multi-touch tables as well as for the smartphones. In addition, by wrapping Citizen information into the NFC Data Exchange Format (NDEF), mobile devices can deduce which applications are able to handle the information stored in an NFC tag. This would allow smartphones to immediately launch a corresponding application once an NFC tag is read and pass on the information from the NFC tag. The application would then be able to extract Citizen information and set up a connection with available objects or devices.

# Part II

# Research

# Chapter 4
# Evaluating Usability and Limitations

From the literature in chapter 2 it becomes clear that both mobile and stationary technologies have their individual strengths but also their own limitations. In the methodology a new strategy is set out to overcome these limitations and a first study investigating the strategy is described in this chapter.

## 4.1 Introduction

The purpose of the study described in this chapter is twofold. First of all, to examine the usability of combinations of mobile and stationary technologies, and secondly to identify barriers and challenges emerging from novel interaction methods. It is expected that combining these technologies can help overcome these limitations but will also give rise to new challenges. Identifying these challenges will provide valuable insights for following studies. Additionally, the study will demonstrate the idea of pervading exhibits and how these can be put into practice.

## 4.2 Methodology

The literature review in chapter 2 identified some of the problems that arise when museums apply technological innovations in their environments for visitor engagement. In chapter 3.1 the concept of pervading exhibits was introduced. Within pervading exhibits objects and both mobile and stationary technologies become part of a larger interconnected system to overcome some of the identified problems. McAdam *et al.* studied the effects of different combinations of mobile devices and interactive displays on user performance for a dial manipulation task. Their results suggest that "using a phone and table together can sometimes be better than using the table alone" [58]. However, they also state that when "multiple devices are used, it is important to decide how these devices can be best used together" [58]. Moreover, how combinations of mobile and stationary technologies, and the interaction modalities that emerging from this, influence users is something to be investigated. This forms the basis of the study described in this chapter which addresses the following research question:

- What are the effects of combining new technologies in a museum environment on user experiences?

According to Law *et al.* the term 'user experience' is "associated with a broad range of fuzzy and dynamic concepts, including emotional, affective, experiential, hedonic, and aesthetic variables" [54]. In their study Law *et al.* approached researchers and practitioners for their views on the concept of user experience in order to find a common agreement. Results of their study suggest researchers and practitioners "tend to agree on a concept of [user experience] as dynamic, context-dependent and subjective, which stems from a broad range of potential benefits users may derive from a product" [54]. When looking at combinations of mobile and stationary technologies in a museum environment and their influence on user experiences, this is both context-dependent and subjective. Furthermore, any potential benefits are closely related to the usability of the combinations of these technologies. However, how users react to, and cope with, arising usability problems is also influenced by their affective response [62]. For example, frustration would increase users' negative affect [8], whereas a more enjoyable experience would increase users' positive affect [40]. This study will therefore focus on the usability and affective response of the combinations of these technologies. Combining this with the original research question results in the following two research questions:

- What are the effects of combining mobile and stationary technologies in a museum environment on user experiences in terms of usability?
- What are the effects of combining mobile and stationary technologies in a museum environment on user experiences in terms of affect?

In order to find an answer to these research questions the idea of pervading exhibits was put into practice and an experiment was designed to test a number of hypotheses. During the experiment participants were able to interact and engage with museum artefacts using novel interaction modalities combining mobile and stationary technologies in a museum environment. Using questionnaires their perception of usability and affective response could be evaluated.

### 4.2.1 Measuring Affective Response

Although there is a wide variety of dimensions associated with affective responses, according to Picard the three most commonly used emotional dimensions are: valence, arousal, and dominance [66]. To measure these dimensions of affective response the Self-Assessment Manikin (SAM) questionnaire designed by Bradley *et al.* [15] was used. They describe the SAM questionnaire as a "non-verbal pictorial assessment technique that directly measures the pleasure, arousal, and dominance associated with a person's affective reaction to a wide variety of stimuli". Conforming with the original design by Bradley *et al.* a 9-point Likert scale was used in the experiment where higher ratings indicate more pleasure, arousal, or dominance whereas a median rating (i.e. 5) would indicate a neutral experience.

### 4.2.2 Measuring Usability

To measure participants' perception of usability of the combination of technologies the System Usability Scale (SUS) questionnaire was used. The questionnaire, designed by Brooke [18] is a "simple, ten-item scale giving a global view of subjective assessments of usability". Although originally developed to measure systems' perceived ease-of-use, Lewis *et al.* have shown that besides a measure of system satisfaction the SUS questionnaire also provides information about usability and learnability [55]. As the SAM questionnaire was designed with a 9-point Likert scale the same Likert scale was used for the SUS questionnaire where higher ratings indicate a more usable and learnable system.

## 4.3 Experiment

In order to answer the research questions, "What are the effects of combining mobile and stationary technologies in a museum environment on user experiences in terms of usability?" and "What are the effects of combining mobile and stationary technologies in a museum environment on user experiences in terms of affect?", an experiment was designed which will be further described in this section along with how the data was analysed and the participants who took part in the study.

### 4.3.1 Participants

The study ran for five days during which twenty participants (8 female and 12 male), aged between 24 and 42 ($\mu = 32.05, \sigma = 5.89$) took part in the experiment. All participants had normal, or corrected-to-normal vision and all but one described themselves as daily computer users. Out of the 20 participants 15 had experience with digital games and 11 of them had some experience working with virtual 3D models. Before the experiment all participants signed an informed consent form and they were paid according to institution's regulations.

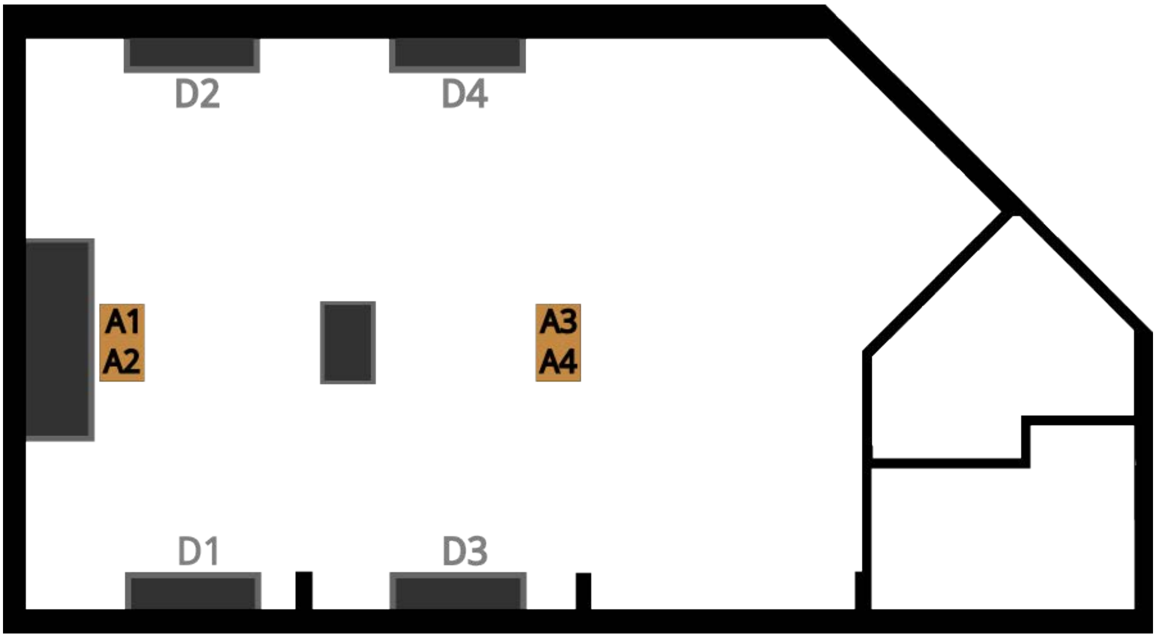
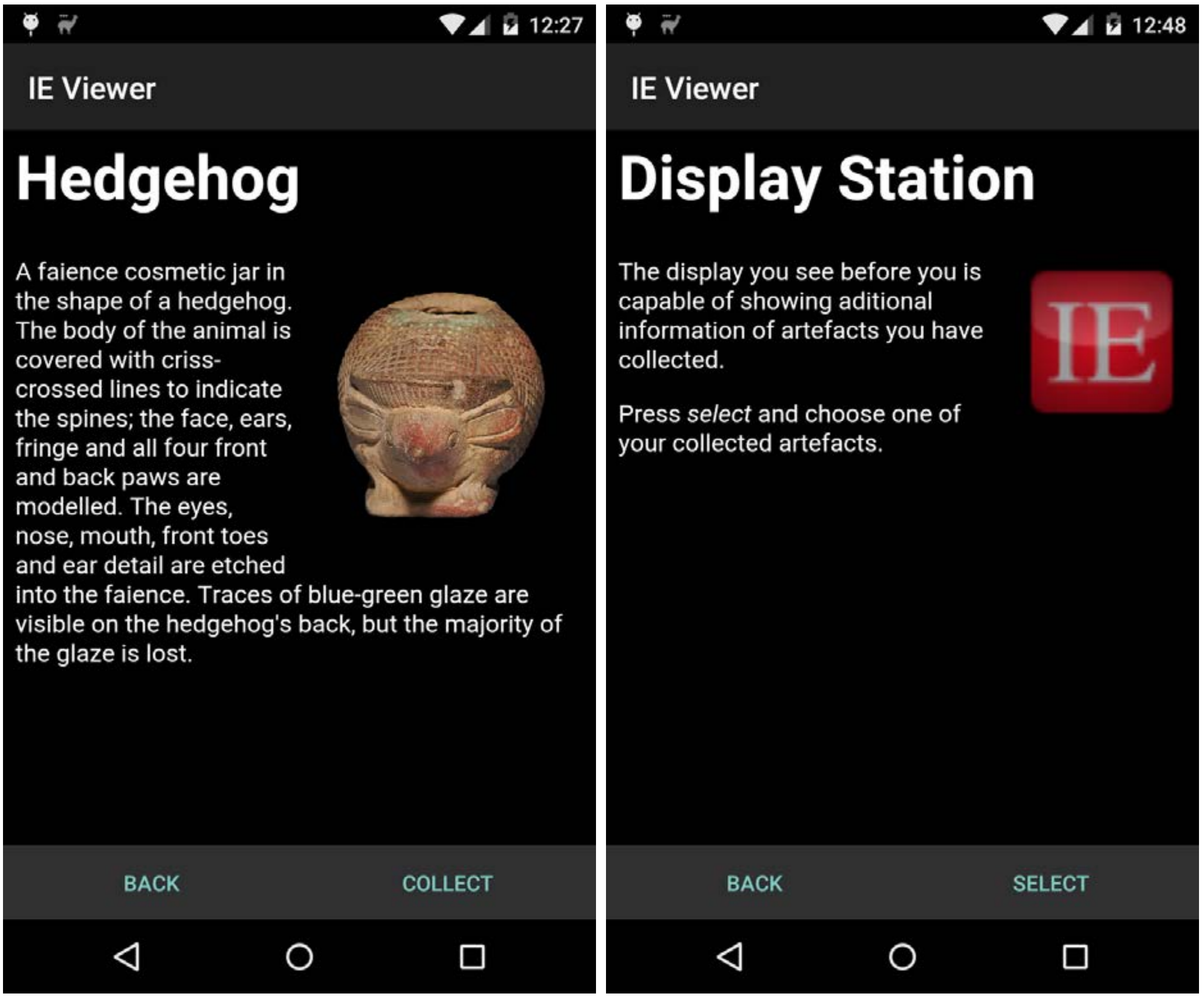



Figure 4.1: Layout of the Hall with four museum artefacts (A1-A4), and four interactive displays (D1-D4)

### 4.3.2 Setup

The experiments held in this study consisted of two different sessions. During each session participants were given the task to organise a small museum exhibition using two different interaction modalities of combinations of mobile and stationary technologies. The experiment was held in the Hall as described in chapter 3.4. In the Hall four museum artefacts were placed on two tables on opposite sides and four interactive liquid-crystal display (LCD) screens were fitted on the walls of the remaining sides of the room (see figure 4.1). Both the museum artefacts and the interactive displays were fitted with NFC tags which allowed participants to interact with them.

To allow participants to interact with the artefacts and carry the interaction throughout the environment onto the interactive displays, they were given an NFC enabled smartphone. On the smartphone an Android application was installed utilising the Sytizen framework described in chapter 3.3. The Android application would launch once a CR was obtained from an NFC tag. Using the CR a connection was established which would, depending on the NFC tag that was scanned, either show artefact information or allow participants to




(a) (b)

Figure 4.2: Smartphone interaction with (a) an artefact, or (b) an interactive display

interact with an interactive display (see figure 4.2).

On the interactive displays an application was running which accepted CRs. Once a CR was received it was used to retrieve the artefact's 3D model, show the 3D model on screen, and allow participants to rotate it. This would allow observing these "artifacts virtually at arbitrary angles and zooming scales on public displays" [27]. It was the participants' task to collect the CRs, load the 3D models onto the displays, and rotate them into a predefined orientation. Which artefact to show on the displays, and how the artefact should be orientated was presented on a paper sheet next to the displays. To rotate the 3D models in order to match the predefined orientation, participants used one of two interaction modalities, the interactive display itself, or the smartphone (see figure 4.3).

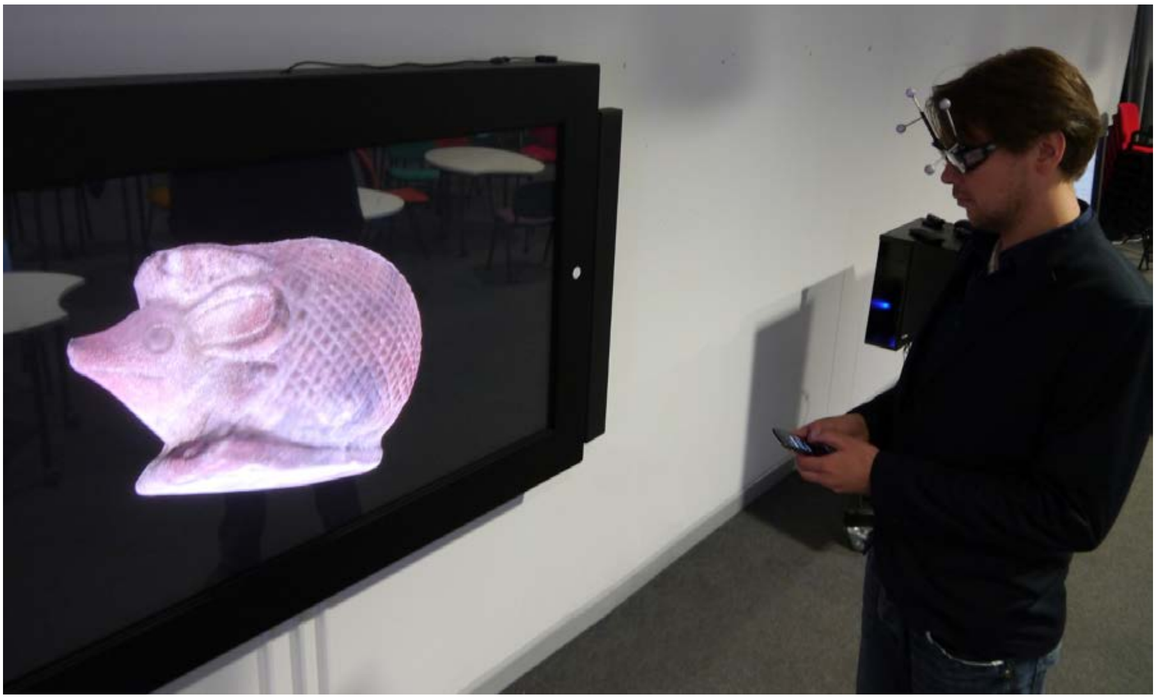


Figure 4.3: Using smartphone to rotate a 3D model of a museum artefact[1]

The conditions were hence called ‘display’ and ‘phone’ respectively. For the ‘display’ condition touching the interactive displays would result in rotating the 3D model along its x or y axis. In the ‘phone’ condition the application running on the interactive display used touch information from the smartphone and rotate the 3D model along its x or y axis as in the ‘display’ condition. For the experiments a within-subjects designs was used and each participant used both interaction methods. However, to avoid confounding variables such as learning the locations of the artefacts a counterbalanced measures design was used. Additionally, 3D models of the artefacts were placed in a random orientation once loaded onto the interactive display. Before each session both smartphone and interactive displays were reset to their initial status.

Before entering the Hall participants were given an information sheet about the study, a short introduction on the procedure of the experiment and were instructed on the use of the smartphone and how to scan the NFC tags (see appendix B). During each session an experimenter was present in the Hall to assist participants where needed and to keep notes.

[1]The glasses with tracking markers were not used during the experiment

### 4.3.3 Data Acquisition

After the introduction participants were asked to complete an online demographics questionnaire (see appendix C). Besides basic information such as age, mother tongue, and level of computer experience, they were asked about their prior experience playing digital games and working with virtual 3D models. The latter two were expected to influence how participants dealt with rotating the 3D models. After each session, participants were asked to complete two questionnaires. First the SAM (see appendix D) and second the SUS questionnaire (see appendix E). After the final session participants were asked which interaction modality they preferred, 'display' or 'phone'.

In terms of perceived usability it was expected that the results would show a strong correlation with the control dimension of the SAM questionnaire and would be rated higher for the 'display' condition compared to the 'phone' condition. However, as users interact with smartphones on a daily basis it was expected that the 'phone' condition would be rated higher than the 'display' condition in terms of learnability. Additionally, as the mode of gestural interaction is similar on smartphones as on multi-user, multi-touch displays (i.e. moving up or down, or left or right would result in a rotation along the y or x axis respectively), it was not expected this would influence participants' affective response. However, as users interact with smartphones on a daily basis it was expected that using a smartphone as part of a novel interaction modality would result in higher ratings for the valence and arousal dimensions for the 'phone' condition, compared to the 'display' condition. As touching the interactive display to interact with 3D models would provide a more direct interaction with the presented model [36], it was also expected that this would result in higher ratings in the control dimension for the 'display' condition compared to the 'phone' condition.

For quantitative data analysis interactions with smartphone and interactive displays were recorded during the sessions. This would provide information about participants' route through the Hall, their interaction time with the artefacts and interactive displays, and the rotations of the 3D models. For the time it took participants to complete the task, measured from the moment they entered the Hall till they left, it was expected that they were able to complete the task faster in the 'display' condition compared to the 'phone' condition due to higher control ratings. The rotations of the 3D models were used to calculate the maximum error of the final orientation of the 3D models (i.e. how accurate were participants in rotating the 3D models to match the provided orientation). As with the task completion time, it was expected that with higher control ratings participants would also be more accurate in the 'phone' condition compared to the 'display' condition. Finally, the experimenter who was present in the Hall was instructed to time participants sessions and note events such as: switching smartphone from hand, whether smartphone or interactive display provided an obstruction, and other difficulties participants encountered.

### 4.3.4 Analysis

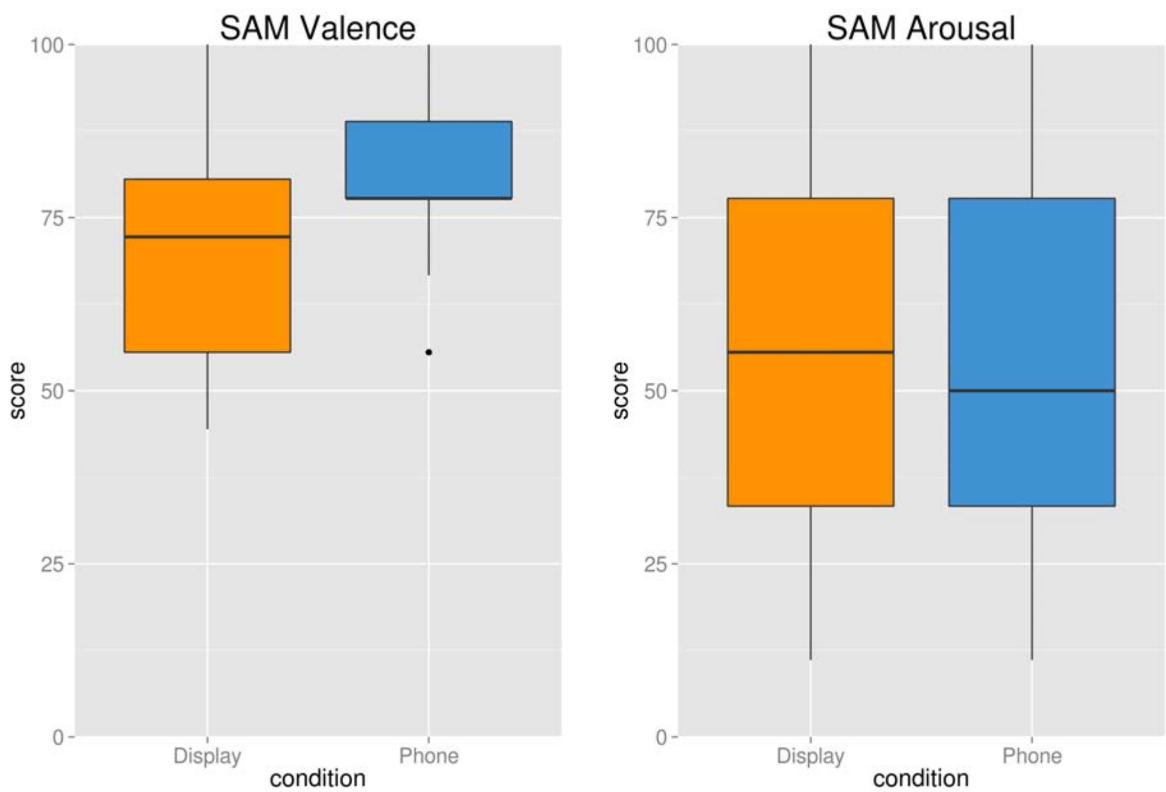
After the experiments ratings for both the SAM and SUS questionnaires were obtained and sub factor ratings were calculated for both of them. All ratings were normalised and extreme values were adjusted to three standard deviations. Ratings were tested for normality and since each participants used both interaction methods, the ratings were compared using either Wilcoxon signed-rank test or Student's t-test to determine if there was a significant difference between the two interaction methods. The same was done for the task completion time and accuracy. For each of the different measurements the Holm-Bonferroni correction was used with a combined significance of $p \leq 0.05$ in case of multiple comparisons.

## 4.4 Results

When asked which interaction modality they preferred, 17 out of 20 participants indicated they preferred the smartphone. In contrast, only 3 participants indicated they preferred using the display. This might suggest participants believed the smartphone interaction to be more user friendly or enjoyable. A more in-depth analysis of the questionnaires and data recordings should provide a better understanding of these statements and further analysis of the results of the questionnaire and data recordings are described in this section.

### 4.4.1 Self-Assessment Manikin

The SAM questionnaire was used to measure participants' affective response while using the interaction modalities to rotate the 3D models during the sessions (e.g. participants found the 'phone' condition to be more frustrating). Looking at the valence and arousal dimensions of the SAM questionnaire (see figure 4.4) there seems to be some difference between the two conditions in terms of valence. The ratings for the arousal dimension however, are almost identical.




(a) (b)

Figure 4.4: Normalised ratings for Valence (a), and Arousal (b)

For the valence dimension a paired-samples t-test (with Holm-Bonferroni correction for three comparisons) indicated that the difference between the 'display' ($\mu = 71.67, \sigma = 16.71$)

condition and the 'phone' ($\mu = 81.11, \sigma = 12.01$) condition was significant, $t(19) = -3.49, p < 0.01$. As for the arousal dimension, no significant difference was found between the 'display' ($\mu = 55.56, \sigma = 26.24$) condition and the 'phone' ($\mu = 52.22, \sigma = 27.24$) condition, $t(19) = 1.14, p = 0.27$.

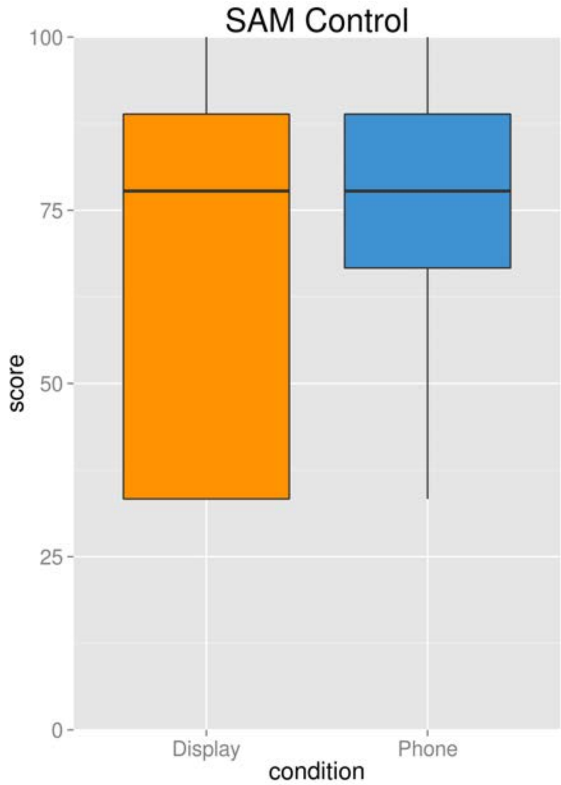



Figure 4.5: Normalised ratings for Control

For the control dimension it was expected that the 'display' condition would rate higher. Even though the ratings of the control dimension appear to be equal (see figure 4.5), a Wilcoxon matched-pairs signed-ranks test and Holm-Bonferroni correction for multiple comparisons indicated a significant difference between the 'display' ($\tilde{x} = 77.78$) condition and the 'phone' ($\tilde{x} = 77.78$) condition, $Z = -2.36, p = 0.04$. Although the median values are identical, mean values of the 'display' ($\mu = 66.11$) condition and the 'phone' ($\mu = 77.78$) condition indicate that on average participants rated the 'phone' condition higher in terms of control.

### 4.4.2 System Usability Scale

The SUS questionnaire was used to determine participants' perception of usability and learnability of the two interaction modalities. Looking at the overall perceived ease-of-use (see figure 4.6) there seems to be a small difference between the 'display' ($\mu = 73.64, \sigma = 12.82$) condition and the 'phone' ($\mu = 82.64, \sigma = 10.84$) condition. However, after Holm-Bonferroni correction for multiple comparisons, a Wilcoxon matched-pairs signed-ranks test indicated that this difference was nonsignificant, $t(19) = -2.35, p = 0.09$.

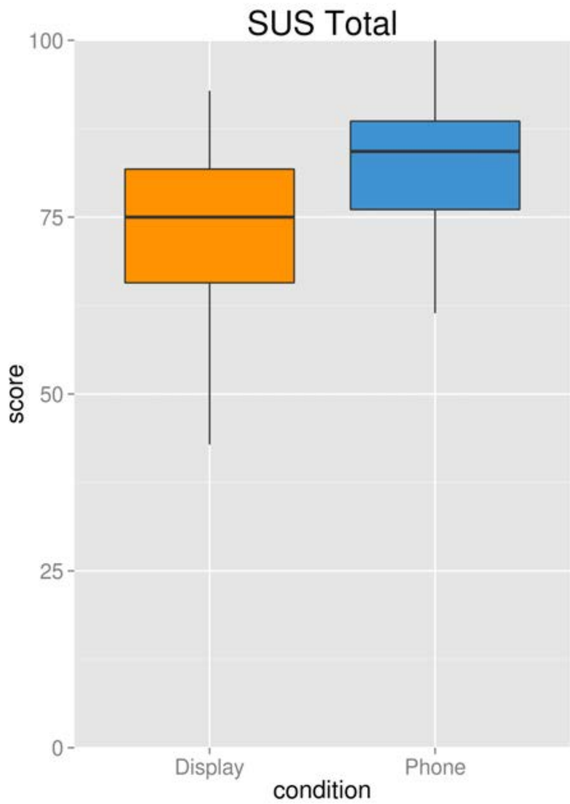
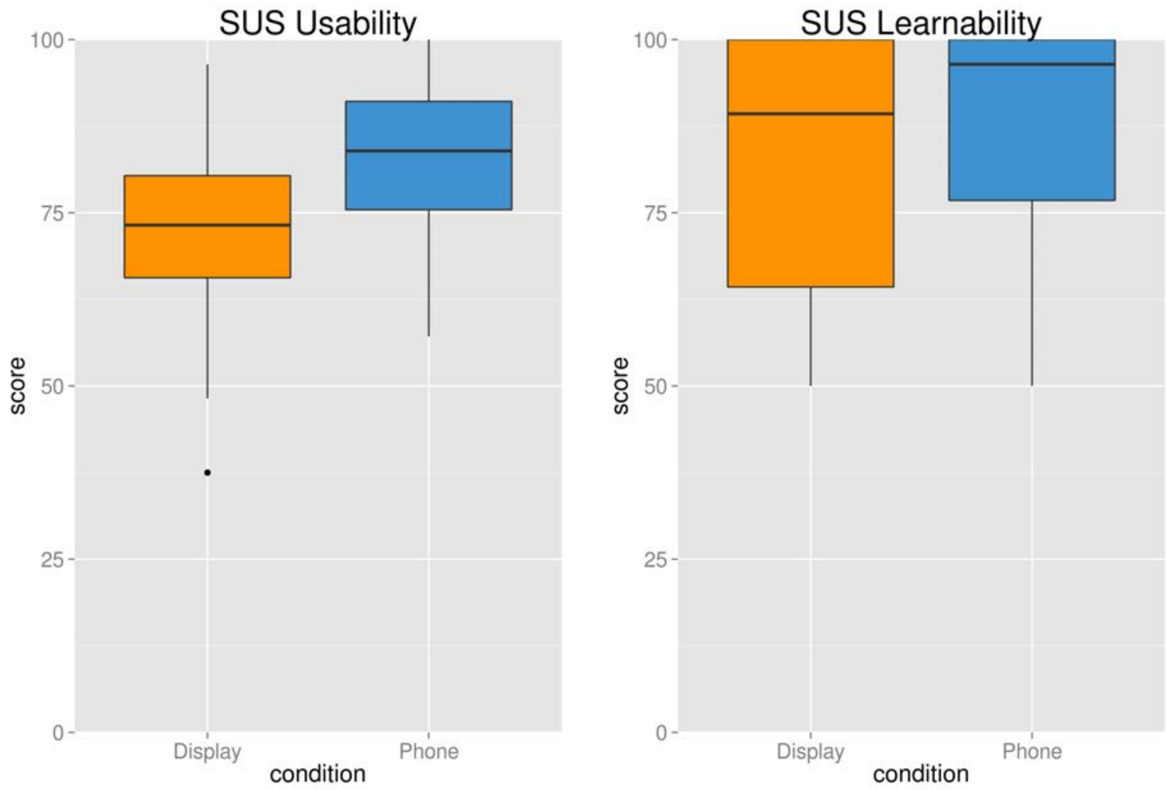



Figure 4.6: Normalised ratings for overall perceived ease-of-use

Further investigation of the SUS questionnaire, looking at the usability and learnability dimensions (see figure 4.7), revealed a similar difference for the usability dimension, whereas for the learnability dimension the two conditions are almost similar. However, for the usability dimension the difference between the 'display' ($\mu = 71.52, \sigma = 14.66$) condition and the 'phone' ($\mu = 81.79, \sigma = 12.12$) condition appeared to be nonsignificant,



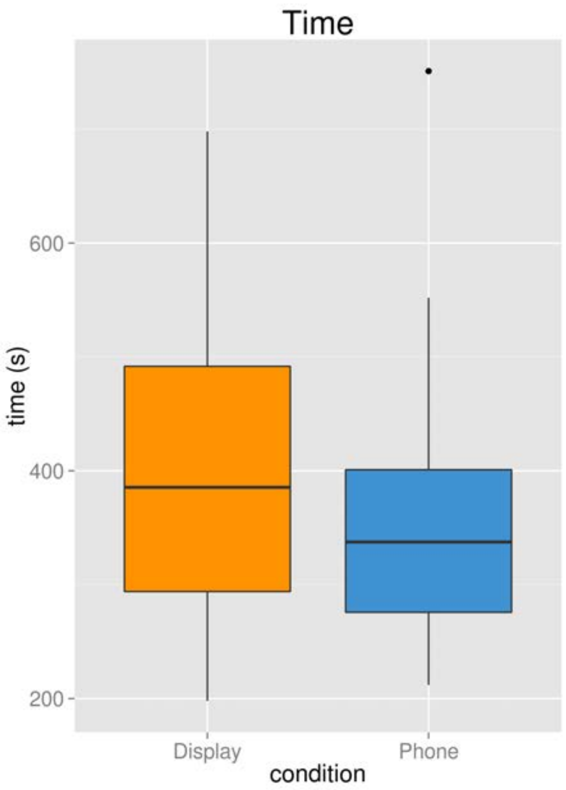

(a) (b)

Figure 4.7: Normalised ratings for (a) usability , and (b) learnability dimensions of the SUS questionnaire

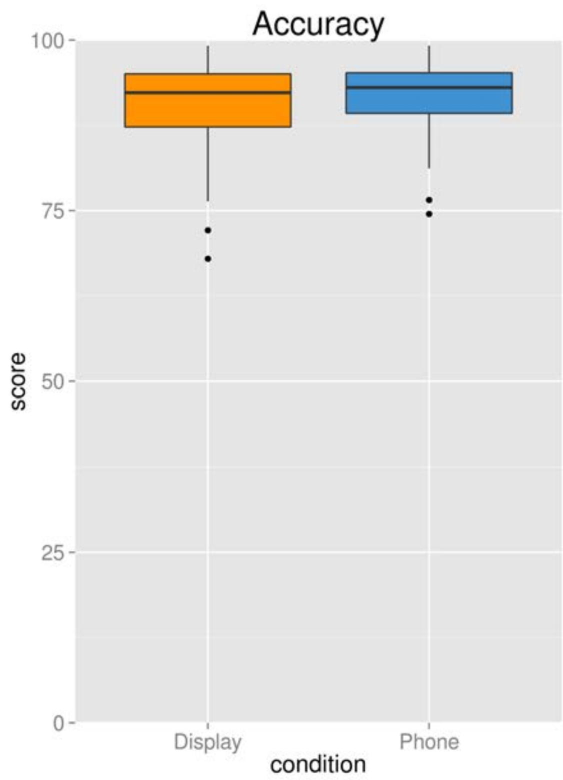
$t(19) = -2.27, p = 0.09$. Also for the learnability dimension, the difference between the 'display' ($\tilde{x} = 89.29$) condition and the 'phone' ($\tilde{x} = 96.43$) condition was nonsignificant, $Z = -1.01, p = 0.31$.

### 4.4.3 Task Completion Time

Overall task completion time for each session was recorded for quantitative analysis and are shown in figure 4.8a. Although there appears to be a difference between the 'display' ($\tilde{x} = 385.5$) condition and the 'phone' ($\tilde{x} = 337.5$) condition this difference was not significant, $Z = -0.80, p = 0.42$.




(a)




(b)

Figure 4.8: Task completion times (a), and normalised ratings for accuracy (b).

### 4.4.4 Task Accuracy

From the recorded interactions the error was calculated as the minimum angle needed to rotate the 3D model to its required orientation. For the accuracy (see figure 4.8b) the difference between the 'display' ($\tilde{x} = 92.28$) condition and the 'phone' ($\tilde{x} = 93.04$) condition was nonsignificant, $Z = -1.13, p = 0.26$.

## 4.5 Discussion

The results of the experiment suggest that the majority of the participants preferred interacting with the 3D models using the smartphone (i.e. 'phone' condition) rather than through direct-touch (i.e. 'display' condition), even though some of them experienced lag in the 'phone' condition due to the wireless network. In terms of affective response, it was expected that the valence and arousal dimensions would show higher ratings for the 'phone' condition compared to the 'display' condition. Although ratings were significantly higher for the 'phone' condition for the valence dimension, the majority of the ratings for the arousal dimension ranged from 30% to 70% in both conditions and were nonsignificant. Overall this would suggest participants were more content during the 'phone' condition.

Furthermore, it was expected that in the 'display' condition, where users touched the 3D models more directly, ratings for the control dimension and accuracy would be higher compared to the 'phone' condition. However, for the task execution accuracy there was no significant difference and for the control dimension results show the opposite. Participants rated the 'phone' condition significantly higher in terms of control compared to the 'display' condition. This matches with participants' preferences which suggest that using the smartphone as an interaction methodology provides users with an indirect input that provides a familiar experience (e.g. a touch pad or mouse). Although the gestural interactions were kept identical for the two conditions, participants seemed to intuitively use the smartphone for fine grained and precise gestures whereas the display interaction invited them for more coarse gestures.

Results of the usability questionnaire were in line with the valence and control dimensions of participants' affective response where participants rated the 'phone' condition higher than the 'display' condition. Although this difference was nonsignificant, it might suggest that rotating a 3D model by touching the display might not be as straightforward as earlier research has shown. Using an additional interface which separates the object from input might have contributed to the increased usability in the 'phone' condition compared to the 'display' condition. Additionally, the learnability scale indicated participants believed they needed time, and possibly help, to learn how to use the interaction modalities. However, experimenters noted participants quickly learned how to use the smartphone to scan NFC tags, and load the models onto the display. As the overall usability received high ratings, this would suggest that although the learning curve was steep, it was also short.

During the sessions, experimenters also observed participants and made notes of their behaviour. First of all experimenters noted that participants stood further away from the displays during the 'phone' condition. Due to physical restraints, participants had to be close to the display to rotate the 3D models during the 'display' condition, whereas rotating the 3D model using the smartphone allowed participants to take a few steps back to observe both the whole display and also the instruction paper hanging next to it. Secondly, during the 'display' condition the smartphone impeded interaction after participants loaded a 3D model onto the display. Participants often switch the smartphones from their dominant to non-dominant hand, put them in their pockets, or in some occasions placed them on nearby tables or on top of the displays. During the 'phone' condition this did not occur as the smartphone was an integral part of the interaction, and participants often strengthened this interaction by holding the smartphone with both hands to gain finer control. These two physical restraints may have impacted on the usability ratings for the 'display' condition.

Overall the results show that participants were equally effective in the tasks given to them, whether using a smartphone or an interactive display. However, participants indicated they preferred using a smartphone to rotate 3D models on a large display rather than using direct-touch. Compared to direct-touch the smartphone interaction modality received significant higher ratings in terms of valence and control. Additionally, the results show that although the learning curve for using new technologies was steep, when designed to work straightforward and without complicated instructions or operations, participants picked these up quickly and were able to swiftly adapt to novel interaction modalities.

Finally, when designing for engaging experiences using combinations of smartphones and interactive displays, a smartphone should be an integral part of the interaction. Using the smartphone only for parts of the interaction will impede further user interaction. This could for example mean to provide a place to put the smartphone which could seamlessly be integrated with the scanning NFC tags. The next step would be to explore these options as well as expanding both the exhibition and number of simultaneous participants to study the influence of combinations of these technologies on groups. In order to answer the fourth research question the next chapter will investigate this.

# Chapter 5
# Evaluating Social and Cognitive Aspects

The study described in chapter 4 examined the usability of combinations of mobile and stationary technologies, and identified barriers and challenges emerging from using novel interaction methods for user engagement. The study described in this chapter builds on the study from chapter 4 and addresses the research question "What are the effects of combining new technologies in a museum environment on group experiences?" by investigating the effects of combining these technologies on groups of users.

## 5.1 Introduction

During the experiment described in chapter 4 participants had to organise a small museum exhibition and rotate 3D models on a large display using two different interaction modalities (i.e. smartphone or direct-touch). After the experiment participants rated these interaction modalities in terms of usability and affective response. The results of the experiment show that participants preferred using a smartphone rather than direct-touch to rotate 3D models on a large display. Participants rated the smartphone based interaction modality significantly higher in terms of valence and control. The results also show that the learning curve for using new technologies was steep. However, participants picked these up swiftly and were able to adapt quickly to novel interaction modalities. Finally, observations during the experiments helped to identify obstacles and design challenges for using combinations of smartphones and interactive displays to support engaging experiences. Findings suggest that when using a smartphone for user interaction it should be treated as an integral part of the intended interaction. Using the smartphone only for part of the interaction will impede further user interaction as the smartphone becomes an inconvenience which the user will try to resolve. These results pave the way for new studies in larger and more vibrant settings.

The focus of the study in chapter 4 was on the usability and challenges of combining mobile and stationary technologies however, it only focused on single users. Although it is not uncommon for people to visit a museum alone, visits to a museum are often seen as social events and people often come in pairs or groups [11]. This is something which has to be taken into account. Boehner *et al.* also express the importance of social awareness and social interaction in museum environments and state that both social interaction and personalisation are “traditionally overlooked in the design of technology for museums” [14]. The purpose of this study is to include this aspect and investigate how combinations of mobile and stationary technologies influence user behaviour and the experience of groups of visitors.

## 5.2 Methodology

The study described in chapter 4 has shown that users adapt quickly to novel interaction modalities but also highlighted a number of important design challenges. One of these design challenges suggests that when using a smartphone for user interaction it should be treated as an integral part of the intended interaction. Kuflik *et al.* came to a similar conclusion and state that “the visitor’s use of technology should be conceived as contributing to one unique experience, and as such it should offer an integrated approach to different aspects of the visit” [52]. So far the study in chapter 4 has demonstrated how pervading exhibits can be put into practice and how novel interaction modalities emerging from combinations of mobile and stationary technologies can influence users' affective response. However, how these novel interaction modalities influence groups of visitors is something to be investigated and forms the basis of the study described in this chapter which addresses the following research question:

- What are the effects of combining new technologies in a museum environment on group experiences?

According to Doering *et al.* [26] visitors' experience of a museum can be divided into four categories: social, objective, cognitive, and introspective. While social and objective experiences relate to visitors' interaction with their surroundings, cognitive and introspective experiences are inherently solitary and relate to visitors' interpretive aspects of the visit. As these experiences are either solitary or social they are inevitably in conflict with each other. Social interactions for example could disrupt the deep thoughts of others and hinder introspective experiences, just as labels, images, and displays speak to the cognitive experience thereby leaving little room for object experiences. By combining mobile and stationary technologies both solitary and social experiences could be supported and provide visitors with the means to control their own personal experience. However, following the study from chapter 4 there is a need to further investigate their influence on visitors' behaviour and experience and look into both the social and cognitive aspect of museum visits. This study will therefore focus on the social and cognitive aspects of the combinations of these technologies. Combining this with the original research question results in the following two research questions:

- What are the effects of combining mobile and stationary technologies in a museum environment on group experiences in terms of social presence?

- What are the effects of combining mobile and stationary technologies in a museum environment on group experiences in terms of cognitive absorption?

In order to find an answer to these research questions the experimental setup of chapter 4 was extended to accommodate groups of visitors. This was done in collaboration with the

Lapworth Museum of Geology which assisted in selecting a set of museum artefacts to set up a temporary museum exhibition at the Hall described in chapter 3.4. To test a number of hypotheses an experiment was designed in which groups of participants could interact and engage with museum artefacts using novel interaction modalities combining mobile and stationary technologies. Using questionnaires their perception of social presence and cognitive absorption could be evaluated.

### 5.2.1 Measuring Social Experience

Visitors often come to museums in pairs or groups and exploring the museum can be a collaborative activity. Which exhibition to visit, which artefacts to examine, and when to rest or relax is thereby the result of visitor interactions [89]. As visitor experience is often determined by their mutual interaction, various studies have investigated how to facilitate visitor interactions within museum environments to create different visiting experiences.

In a study by Grinter *et al.* museum visitors were provided with the means to listen into each others' audio guides. Although their study targeted paired companions, the added functionality to the audio guide seemed to increase visitors' sense of awareness of others around them [33]. In a related study by Boehner *et al.* visitors were given a mobile device on which they first had to draw a small sketch. When interacting with a museum artefact, participants were able to see the sketches of visitors who had also interacted with the artefact. As visitors left traces when interacting with museum artefacts and other visitors were able to view these traces, they were made aware of the presence of previous visitors [14]. Also, Cosley *et al.* reported visitors "felt a strong sense of the presence of others" [21] while viewing other visitors' traces. Although these studies are different in terms of the visiting experiences, they all create a sense of awareness for museum visitors.

As the concept of awareness is used in a variety of studies within HCI, all with slightly different definitions, Biocca *et al.* express the need for a clear definition and laid the foundation for social presence. They define social presence as a "level of awareness of the co-presence of another human, being or intelligence" [10] which embraces the three dimensions:

co-presence, psychological involvement, and behavioural engagement. As it would be valuable to measure people's perceived level of social awareness, they also developed the 'Networked Minds Social Presence Inventory' [9], a questionnaire which measures four other factors besides co-presence: attentional engagement, emotional contagion, comprehension, and behavioural interdependence. As the questionnaire addresses people's perception of awareness of others in the same environment and the effect they have on them, its construct could be used to measure a social experience within a museum environment.

For measuring participants' perception of social presence the 'Networked Minds Social Presence Inventory' developed by Biocca *et al.* [9] was used. The questionnaire contains 34 statements with which participants could agree or disagree on a 7 point Likert scale. Besides co-presence the questionnaire measures four other factors: attentional engagement, emotional contagion, comprehension, and behavioural interdependence. Although the questionnaire is aimed at mediated interactions, such as teleconferencing, its constructs fit the scope of this study. However, key terms were amended to fit the experiment better (i.e. "my partner" was amended to "my group", and "room" was amended to "exhibition").

### 5.2.2 Measuring Cognitive Experience

Although originally originating from psychology, cognitive experience, or cognitive engagement is deeply rooted within the field of HCI research where it has been described as "a state encompassing the three dimensions, attention focus, curiosity, and interest" [91]. According to Webster *et al.* [91] cognitive engagement concerns users' intrinsic motivations to fulfil their need for pleasurable and satisfying experiences.

In studies by Agarwal *et al.* cognitive engagement was further investigated. They included the notion of 'control' and 'temporal dissociation' into a construct they called 'cognitive absorption' and defined this as "a state of deep involvement with software" [1]. They identified five factors of cognitive absorption: temporal dissociation, focused immersion, heightened enjoyment, control, and curiosity. To measure these factors, as well as cognitive absorption, they also developed a questionnaire which has been used to study users' acceptance in relation to users' beliefs [1], perceived enjoyment and intention to use [93], and perceived ease of use and perceived enjoyment [72]. Although cognitive absorption describes users' reactions towards information technology, its construct also fit a cognitive experience within a museum environment. Especially when examining user behaviour and experience within a digitally mediated museum exhibition.

To measure participants' involvement with the temporary exhibition, Agarwal's *et al.* questionnaire [1] on cognitive absorption was used. For 42 statements participants could indicate their level of agreement or disagreement on a 7 point Likert scale. Agarwal's *et al.* questionnaire measures cognitive absorption in five sub factors: temporal dissociation, focused immersion, heightened enjoyment, control, and curiosity which fit the scope of this study. As with the 'Networked Minds Social Presence Inventory', key terms were amended to fit the experiment better (i.e. "the web" was amended to "the exhibition")

## 5.3 Experiment

In order to answer the two research questions, "What are the effects of combining mobile and stationary technologies in a museum environment on group experiences in terms of social presence?" and "What are the effects of combining mobile and stationary technologies in a museum environment on group experiences in terms of cognitive absorption?", an experiment was designed which will be further described in this section, along with how the data was analysed and the participants who took part in the study.

### 5.3.1 Participants

During the study 36 participants (16 female and 20 male), aged between 19 and 57 ($\mu = 27.11, \sigma = 7.69$) took part in the experiment. All participants were university students from both IT and non-IT related studies and described themselves as at least a 'frequent computer user'. The majority of the participants (29 out of 36) had visited a museum within the last three months, and indicated visiting museums with friends (27 out of 36), family (19 out of 36), their partner (19 out of 36) or alone (12 out of 36). Before the experiment all participants signed an informed consent form and they were paid according to institution's regulations.

### 5.3.2 Setup

For the experiment in this study the experimental setup of chapter 4 was extended to accommodate groups of participants. In collaboration with the Lapworth Museum of Geology a set of museum artefacts was selected and used to set up a temporary museum exhibition at the Hall described in chapter 3.4. In total twenty-four museum artefacts were placed on tables around an interactive tabletop (see figure 5.1). The museum artefacts included rocks, minerals and fossils from all over the world.

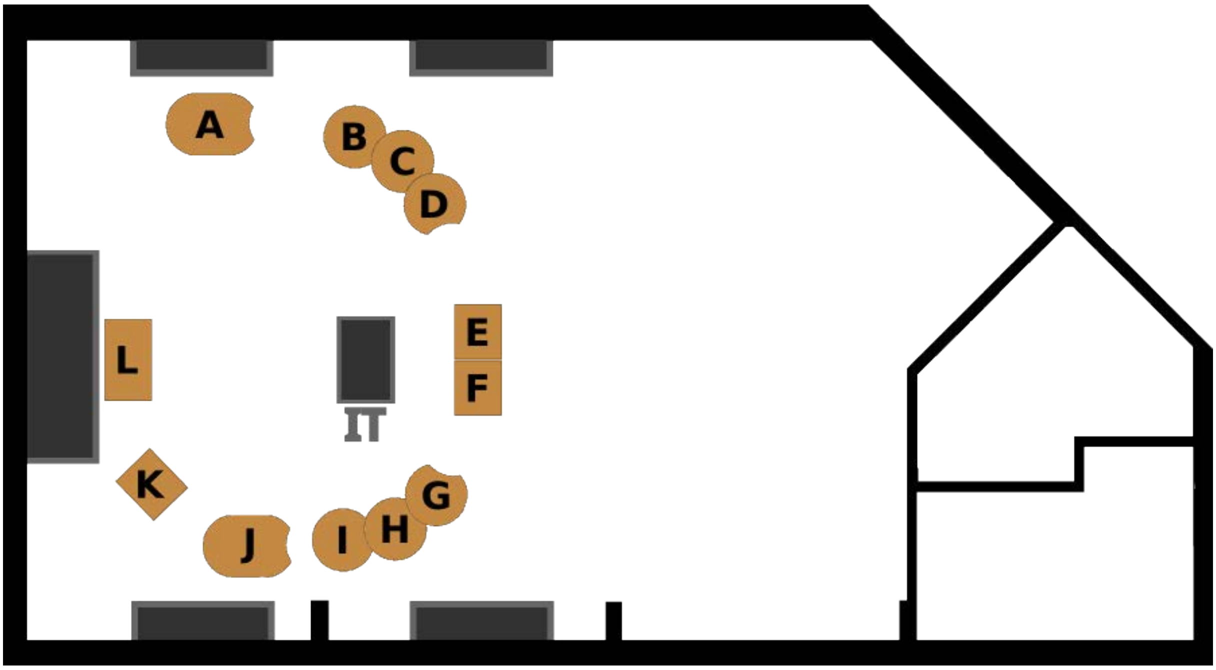



Figure 5.1: Layout of the Hall with the tables for the museum artefacts (A-L), and the interactive tabletop (IT)

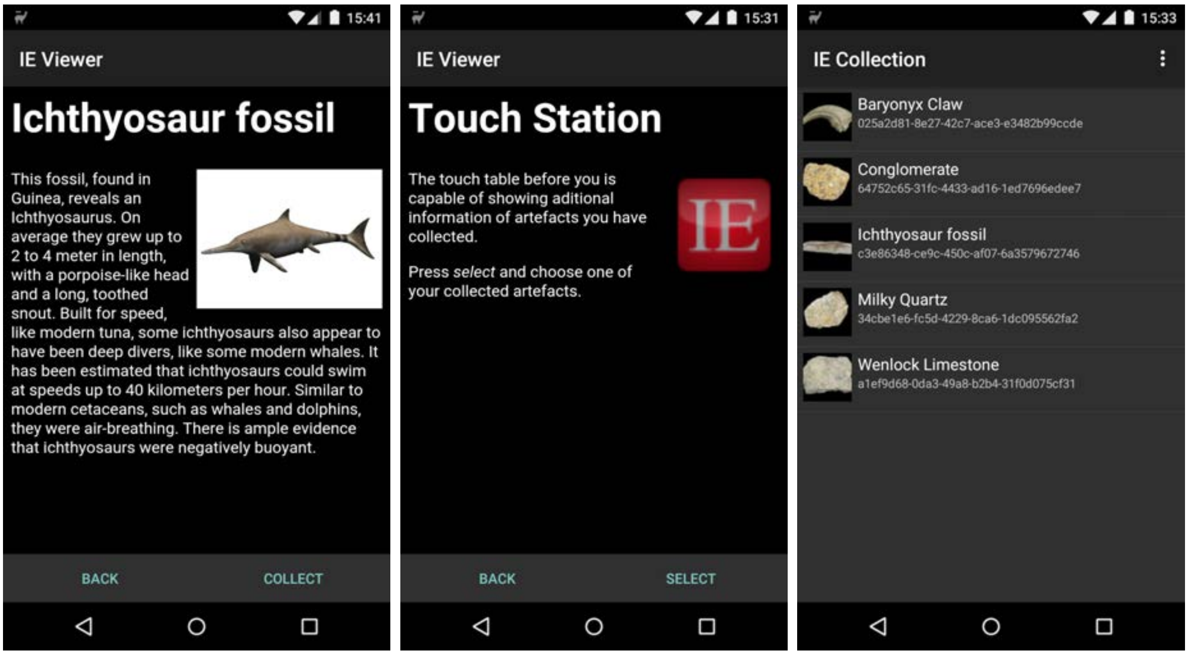
Observations during the study described in chapter 4 suggest smartphones should be treated as an integral part of the intended interaction as they will otherwise impede further user interaction. In order to overcome this challenge NFC tags were embedded in pads which were placed next to the artefacts (see figure 5.2). This seamlessly integrated a place

Figure 5.2: Ichthyosaurus fossil with an NFC pad for user interaction

for participants to put their smartphone with the scanning of NFC tags.

Similar to the experimental setup in chapter 4 participants were given an NFC enabled smartphone to interact with the artefacts. The Android application installed on the smartphone was launched once participants placed their smartphone on one of the NFC pads and the containing NFC tag was scanned. Using the information obtained from the NFC tag, a connection was established which would, depending on the NFC tag that was scanned, either show information about the artefact or allow participants to interact with an interactive tabletop (see figure 5.3). Additionally, participants were able to collect a virtual representation of the artefacts on their smartphone and the Android application allowed participants to view a list of collected artefacts and view artefacts' information at any time.

Additional NFC pads were placed at the centre of each side of the interactive tabletop. When participants placed their smartphone on these NFC pads, the Android application running on the smartphone used the data from the NFC tag to connect with the application running on the interactive tabletop. When a smartphone is connected to the tabletop application, an avatar was shown on the tabletop to illustrate the smartphone was connected.




(a) (b) (c)

Figure 5.3: Smartphone interaction with (a) an artefact[1], or (b) the interactive tabletop, and (c) showing a list of collected artefacts

Participants could then select and send collected artefacts from their smartphone to the tabletop application. Once an artefact was received by the tabletop application, its information was retrieved and a thumbnail was placed in a circle around the participant's avatar. Participants were able to interact with the artefacts presented on the tabletop application. They could drag the artefacts around or tap them to show markers on the world map which would indicate the location where they were found (see figure 5.4).

During the study, groups of three participants visited the temporary museum exhibition in sessions of 15 minutes. As museum-goers tend to visit museums with people they are familiar with (e.g. friends or family) [11], social boundaries have already been crossed. However, in order to emphasise the socialising potential of the interactive tabletops, for the study individuals were invited and were placed in groups of three (see table 5.1). On arrival the participants were given an information sheet about the study (see appendix F), a short introduction on the procedure of the experiment and were instructed on the use of

[1] "Ichthyosaurus communis, Early Jurassic of England" by Nobu Tamura is licensed under CC BY 3.0 (https://creativecommons.org/licenses/by/3.0/legalcode)


Figure 5.4: Tabletop application showing avatar, collected artefacts, and locations of where artefacts were found

the smartphone and NFC pads. Each participant was given a smartphone and glasses with tracking markers after which the group was directed to the temporary museum exhibition. Visits lasted between 10 to 15 minutes after which they were collected and were asked a few questions about the temporary museum exhibition prior to completing three more questionnaires.

To avoid confounding variables such as familiarity with the exhibition, or technology, a between subjects design was used and groups were randomly assigned to one of two conditions. In addition, as this experiment studies the combination of technologies, this is also the first condition. During this condition participants could interact with both the artefacts and the interactive tabletop through their smartphone. As this experiment

| Group | Age | Gender | Mother Tongue | Acquaintanceship |
|---|---|---|---|---|
| **1** | 22.33 ( 2.08) | 1F / 2M | 1 English<br>2 Malayalam | Two met before |
| **2** | 23.33 ( 3.79) | 2F / 1M | 1 Arabic<br>1 Dutch<br>1 English | Two met before |
| **3** | 40.33 (16.04) | 1F / 2M | 1 Dutch<br>2 English | Strangers |
| **4** | 23.67 ( 4.51) | 1F / 2M | 3 English | Strangers |
| **5** | 20.67 ( 1.15) | 2F / 1M | 1 Cantonese<br>1 English<br>1 Romanian | Strangers |
| **6** | 23.00 ( 2.00) | 2F / 1M | 1 Chinese<br>2 English | Strangers |
| **7** | 27.67 ( 2.52) | 2F / 1M | 1 English<br>1 Italian<br>1 Portuguese | Two are acquainted |
| **8** | 29.33 ( 9.29) | 1F / 2M | 1 Chinese<br>2 English | Strangers |
| **9** | 33.00 ( 7.00) | 1F / 2M | 2 Chinese<br>1 English | Strangers |
| **10** | 27.00 ( 3.46) | 3M | 1 Arabic<br>2 English | Two met before |
| **11** | 24.00 ( 4.58) | 3F | 3 English | Two met before |
| **12** | 31.00 ( 6.08) | 3M | 3 English | Two met before |

Table 5.1: Compositions of the groups, showing age (represented as $\mu(\sigma)$), gender (represented as Female / Male), mother tongue and acquaintanceship.

is not looking to compare mobile with stationary technologies, the second condition would need only one of the two technologies. As only an interactive tabletop would not allow participants to interact with the museum artefacts, this would introduce additional dependent variables. Therefore, during the second condition only the NFC pads around the interactive tabletop were removed. This still allowed participants to interact with the artefacts through their smartphone, but turned the tabletop into a static map of the world. The conditions were hence labelled ‘interactive’ and ‘static’ respectively. To keep both conditions as similar as possible the location of where artefacts were found was also added in their description for both conditions.

### 5.3.3 Data Acquisition

On arrival, and before taking part in the study, participants were asked to complete an online demographic questionnaire (see appendix G). After their visit to the temporary museum exhibition, participants were requested to complete three online questionnaires (in random order). To measure participants' perception of social presence, the 'Networked Minds Social Presence Inventory' was used (see appendix H). For measuring participants' engagement with the temporary museum exhibition Agarwal's *et al.* questionnaire [1] on cognitive absorption was used (see appendix I). Additionally, as the design of the application on the interactive tabletop could potentially lead to a more frustrating [8], or enjoyable experience [40], a third questionnaire was added to measure participants' affective response. For this the PANAS-X [90] was used, a more extensive questionnaire compared to the SAM questionnaire in the study described in chapter 4 (see appendix J). Additionally, participants' movements were tracked within the temporary museum environment. The Hall in which the temporary museum exhibition was held is equipped with a tracking system (see chapter 3.4) and before entering the Hall participants were given glasses with tracking markers. During their visit these tracking markers allowed tracking of their location and gaze direction. A separate system recorded participants' location and gaze direction at 10 frames per second which was later used to calculate the distance between participants and the time participants spent alone, in pairs, or as a trio at artefacts or at the interactive tabletop.

In order to identify any abnormalities in the data, a video camera was mounted on a tripod providing a bird's-eye view of the temporary exhibition and recorded participants interactions during their visit (see figure 5.5). First and foremost this would provide a validation for the tracking data as well as investigating abnormalities in the data. However, video recording can later be used for further analysis of participants' interaction, potentially looking for social cues, such as different type of gestures (e.g. emotional, informative, instructive).


Figure 5.5: A bird's-eye view of the temporary museum exhibition during one of the sessions. A group of three participants could interact with 24 museum artefacts which were placed on tables around an interactive tabletop. Both the artefacts and the interactive tabletop were fitted with NFC pads.

### Social Presence

In terms of social presence it is expected that the interactive tabletop will draw participants closer together over a longer period in the 'interactive' condition. As this will potentially force participants to pay more attention to their group members, this will result in higher levels of the factors co-presence and attentional engagement in the 'interactive' condition compared to the 'static' condition. Since the groups consist of individuals who have had little to no prior interaction with each other, no differences are expected for the other three factors (i.e. behavioural interdependence, emotional contagion and comprehension).

### Cognitive Absorption

As the interactive tabletop in the 'interactive' condition will potentially offer a more engaging experience, it is also expected that participants will be more involved with the exhibition. It is therefore expected that this will result in higher levels of cognitive absorption and its factors temporal dissociation and focused immersion. For the other factors (i.e. heightened enjoyment, control and curiosity) no differences are expected.

### PANAS-X

In case any differences in social presence or cognitive absorption are revealed during the analysis of the experiment results, the results of the PANAS-X questionnaire will be used to determine whether participants' affective response could have had an effect on the finding.

### User Tracking

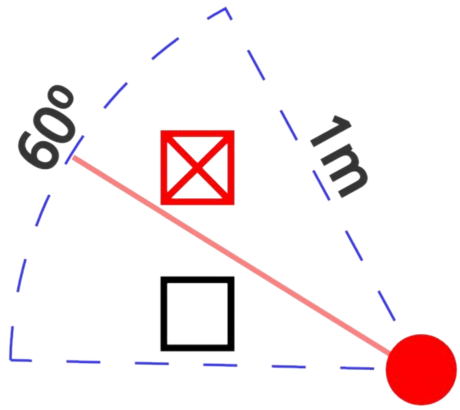
Tracking participants' movements will give quantitative data for which a number of different observations are expected. First of all it is expected that some artefacts will be more popular than others and that participants will spend more time interacting with these artefacts compared to other, less popular, artefacts. Secondly it is expected that participants will spend more time at the interactive tabletop, and in return less time with the artefacts, in the 'interactive' condition compared to the 'static' condition. Finally, as it is expected that the interactive tabletop will draw participants together over a longer period, it is also expected that the average distance between participants will be smaller in the 'interactive' condition compared to the 'static' condition.

In addition, in order to get insights in the implications of the distance between participants, this should be further analysed. As physical distance allows for different interactions, these can be quantified and researchers have tried to define different interaction zones. Streitz *et al.* [83] defined three 'Zones of Interaction' (i.e. ambient, notification and interaction) and Brignull *et al.* [17] defined three similar 'Activity Spaces' (i.e. peripheral awareness, focal awareness and direction interaction). However, these zones (or spaces) have been defined in relation to interactions with technology. Ballendat *et al.* [6] took a different approach and applied concepts from sociology and anthropology to define interactions with technology. They based their research on proxemic theory which Hall describes as the "interrelated observations and theories of man's use of space as a specialized elaboration of culture" [35]. In his work Hall correlates physical distance with different social zones and as "people can be cramped by the spaces in which they have to live and work" and "may even find themselves forced into behavior, relationships, or emotional outlets" [35], insights in the implications of the distance between participants might also be of interest when looking at interaction between them. Hall defines four social zones, intimate ($<$ 45 cm), personal (45 - 120 cm), social (120 - 360 cm) and public ($>$ 360 cm). As it is expected that the interactive tabletop will draw participants together it is also expected that participants will spend less time in the public zone and more time in the social zone during the 'interactive' condition compared to the 'static' condition.

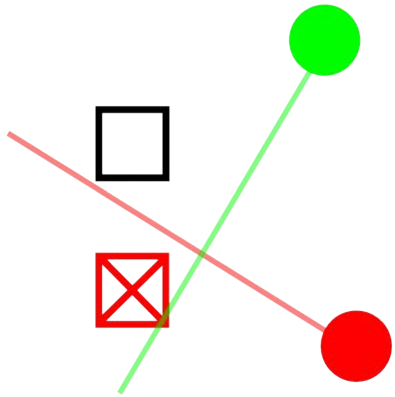
### 5.3.4 Analysis

After the experiments the tracking data was processed to extract the distance and time participants spent together, the time participants spent at the interactive tabletop, and the time participants spent at the artefacts. The latter two were extracted by combining the location and gaze direction of participants with the exact location of the points of interest to determine at which point of interest a participant was spending time. First, only points of interest within 1 meter of a participant were selected. From this subset only points of interest within a 60 degree viewing angle of the participants were kept. Finally, rather than selecting the closest point of interest to the participant's location, the point of interest closest to the participant's gaze direction was selected (see figure 5.6). Additionally, when the gaze direction of participants intersected, the point of interest closest to the intersection was selected. Once a point of interest was selected it was assigned to the participant for that specific frame.

Also the ratings for the five constructs of social presence, cognitive absorption and its five factors, and for the PANAS-X questionnaire were obtained. All questionnaire ratings, the distance and time participants spent together, the time participants spent at the interactive tabletop, and the time participants spent at the artefacts were then normalised and extreme values were adjusted to 3 standard deviations. Values were then tested for normality and appropriate tests (either Mann-Whitney U test, or independent samples t-test) were used to determine if there was a significant difference between the 'static' and 'interactive' conditions. In case of multiple comparisons the Holm-Bonferroni correction was used with a combined significance of $p \leq 0.05$ for each of the different measurements.




(a)



(b)

Figure 5.6: Illustration of post-processing analysis of tracking data with two points of interest depicted as squares. Participants' location and gaze direction in red and green. The point of interest closest to participant's gaze direction was selected (a), or, in case when the gaze direction of two participants intersected, the point of interest closest to the intersection (b).

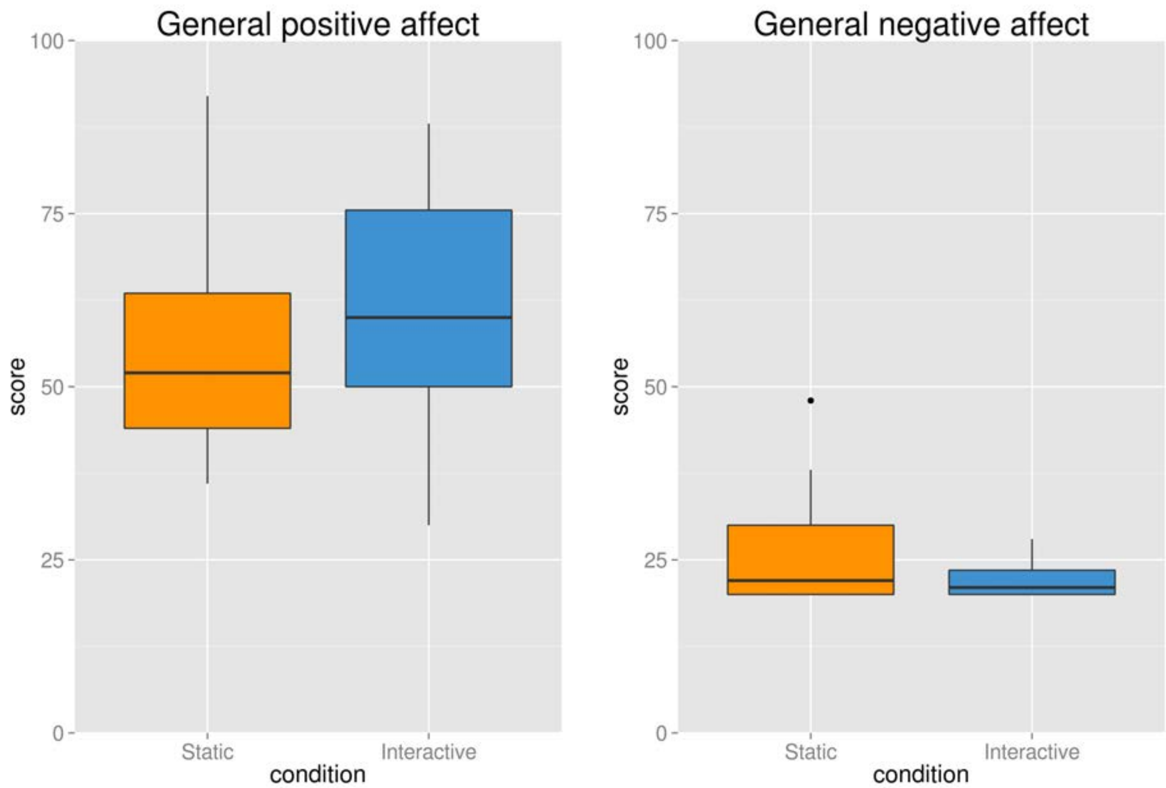
## 5.4 Results

The following section begins with presenting the analysis of the results of the questionnaires, followed by the analysis of the quantitative data, and then compares and relates the different perspectives to provide a complete overview.

### 5.4.1 Questionnaires

#### PANAS-X

The PANAS-X questionnaire was used to establish a baseline in participants' affective response for visiting the temporary exhibition and to rule out possible effects of the used technologies (e.g. participants feeling more frustrated during the 'interactive' condition). Looking at the two higher order scales of the PANAS-X questionnaire, general positive affect and general negative affect (see figure 5.7), it is clear there is little difference between the two conditions in the higher order scales.




(a) (b)

Figure 5.7: Normalised ratings for general positive affect (a), and general negative affect (b).

For the general positive affect a Mann-Whitney U test (with Holm-Bonferroni correction for seven comparisons) indicated no significant difference between the 'static' ($\tilde{x} = 52$) and the 'interactive' ($\tilde{x} = 60$) conditions, $Z = -1.36, p = 0.74$. Similar for the general negative

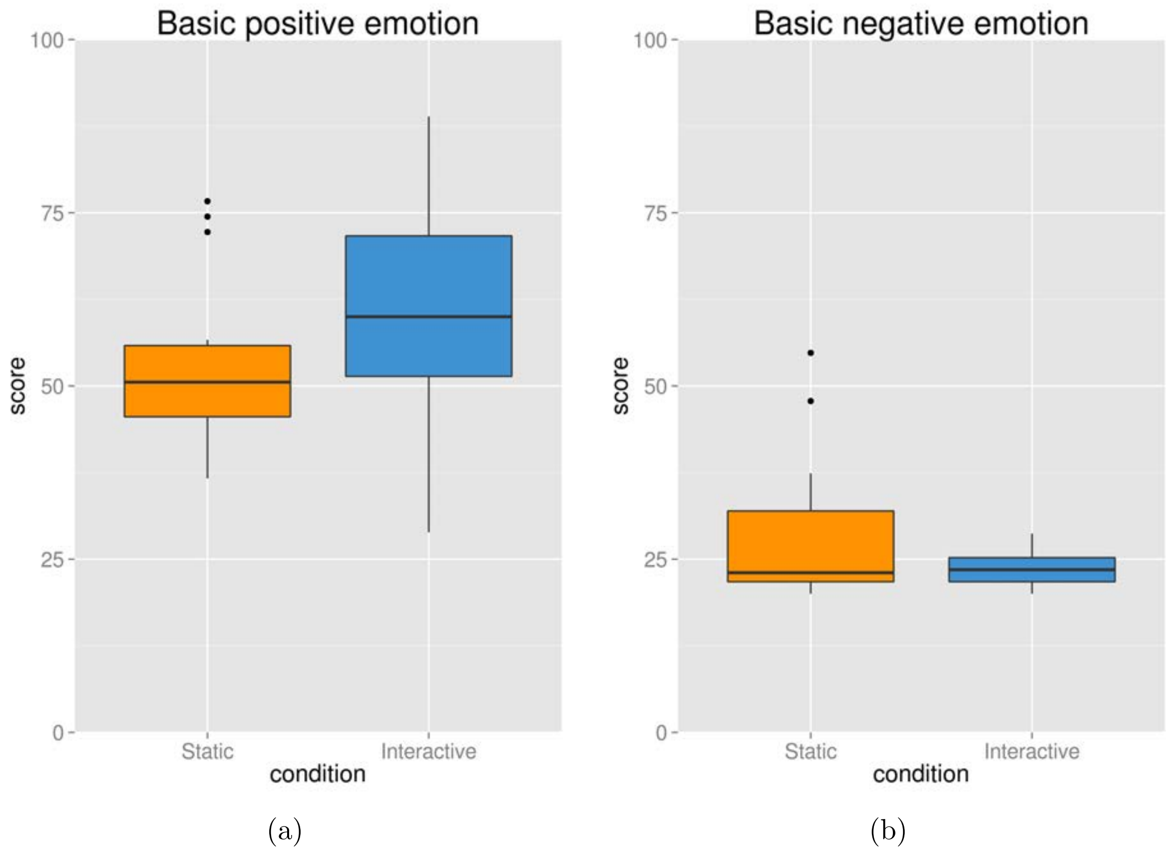



Figure 5.8: Normalised ratings for basic positive emotion (a), and basic negative emotion (b).

affect no significant difference was found between the 'static' ($\tilde{x} = 22$) and the 'interactive' ($\tilde{x} = 21$) conditions, $Z = -0.96, p = 1.00$.

Additionally, the second order scales, basic positive emotion and basic negative emotion were also analysed (see figure 5.8). Although there appears to be a slight difference between the two conditions for the basic positive emotion scale, a Mann-Whitney U test indicated there was no significant difference between the 'static' ($\tilde{x} = 50.56$) and the 'interactive' ($\tilde{x} = 60$) conditions, $Z = -1.68, p = 0.64$. Similar for the basic negative emotion scale, no significant difference was found between the 'static' ($\tilde{x} = 23.04$) and the 'interactive' ($\tilde{x} = 23.48$) conditions, $Z = -0.19, p = 1.00$.

To further explore the slight difference between the two conditions in the basic positive emotion scale, its lower level scales, joviality, self assurance, and attentiveness were investigated (see table 5.2). None of these sub scales showed a significant difference

| | Static | Interactive |
|---|---|---|
| **Joviality** | 50.00 (16.85) | 61.25 (16.22) |
| **Self Assurance** | 43.33 (15.31) | 58.33 (14.66) |
| **Attentiveness** | 67.50 (15.16) | 65.00 (14.94) |

Table 5.2: Normalised ratings for the three sub scales for basic positive emotion. Values are represented as $\tilde{x}(\sigma)$.

between the two conditions. In terms of affective response of the participant no significant difference was found between the 'static' and 'interactive' conditions.

### Social Presence

Secondly the results of the 'Networked Minds Social Presence Inventory' (see table 5.3) were analysed. It was expected that participants in the 'interactive' condition would rate the factors co-presence and attentional engagement higher. For the co-presence factor no significant difference was found between the 'static' ($\mu = 60.22, \sigma = 17.25$) and the 'interactive' ($\mu = 67.86, \sigma = 15.24$) conditions, $t(33) = -1.41, p = 0.54$ (after Holm-Bonferroni correction for five comparisons).

| | Static | Interactive |
|---|---|---|
| **Co-presence** | 61.61 (17.25) | 69.64 (15.24) |
| **Attentional Engagement** | 46.43 (16.28) | 60.71 (15.74) |
| **Emotional Contagion** | 58.04 (11.47) | 52.68 (13.67) |
| **Comprehension** | 71.43 (12.82) | 65.48 (11.17) |
| **Behavioural Interdependence** | 63.10 (12.25) | 55.95 (14.38) |

Table 5.3: Normalised ratings for the five factors of social presence. Values are represented as $\tilde{x}(\sigma)$.

Looking at the attentional engagement factor there seems to be a difference between the 'static' ($\mu = 48.94, \sigma = 16.28$) and the 'interactive' ($\mu = 61.38, \sigma = 15.74$) conditions. This would suggest participants paid more attention to, and were more aware of, the action of their group members in the 'interactive' condition. However, after Holm-Bonferroni correction no significant difference was found between the two conditions, $t(34) = -2.33, p = 0.13$. For the other three factors of social presence (i.e. emotional contagion, comprehension and behavioural interdependence) no differences were expected. For emotional contagion the analysis also showed no significant difference, $t(33) = 1.53, p = 0.54$. Similarly, analysing comprehension and behavioural interdependence showed no significant differences, $t(33) = 1.02, p = 0.54$ and $t(33) = 1.48, p = 0.54$ respectively.

### Cognitive Absorption

Finally, the results of the Cognitive Absorption questionnaire were analysed (see table 5.4). Since the interactive tabletop in the 'interactive' condition offered a more engaging experience for the participants it was expected they would show higher ratings for the factors temporal dissociation and focused immersion. Looking at the results it is clear participants gave high ratings to all factors, especially for the factors curiosity, heightened enjoyment, and temporal dissociation.

| | Static | Interactive |
|---|---|---|
| **Cognitive Absorption** | 74.64 ( 7.52) | 77.50 ( 6.86) |
| **Temporal Dissociation** | 80.00 (14.66) | 78.57 (10.21) |
| **Focused Immersion** | 67.14 ( 7.50) | 64.29 ( 9.09) |
| **Heightened Enjoyment** | 82.14 (10.56) | 83.93 ( 7.96) |
| **Control** | 73.81 (12.38) | 78.57 (11.20) |
| **Curiosity** | 85.71 (11.32) | 80.95 (10.39) |

Table 5.4: Normalised ratings for cognitive absorption and its five factors. Values are represented as $\tilde{x}(\sigma)$.

However, the high ratings are visible for both the 'static' and 'interactive' condition, and after Holm-Bonferroni correction for six comparisons no significant difference was found for the higher order scale, cognitive absorption, between the 'static' ($\mu = 74.68, \sigma = 7.52$) and the 'interactive' ($\mu = 76.39, \sigma = 6.86$) conditions, $t(34) = -0.71, p = 1.00$. Additionally, no significant differences were found between the two conditions for the factors temporal dissociation and focused immersion, $t(30) = -0.64, p = 1.00$, and $t(33) = -0.11, p = 1.00$ respectively.

### 5.4.2 User Tracking

#### Time spent together

For each session the average distance between the three participants was calculated (see figure 5.9). It was expected that the average distance between participants would be smaller during the 'interactive' condition compared to the 'static' condition. A Wilcoxon signed-rank test revealed a significant difference between the 'static' ($\mu = 362.70, \sigma = 153.61$) and 'interactive' ($\mu = 316.50, \sigma = 138.22$) condition, $Z = -15.27, p < 0.001$ (after Holm-Bonferroni correction for five comparisons).

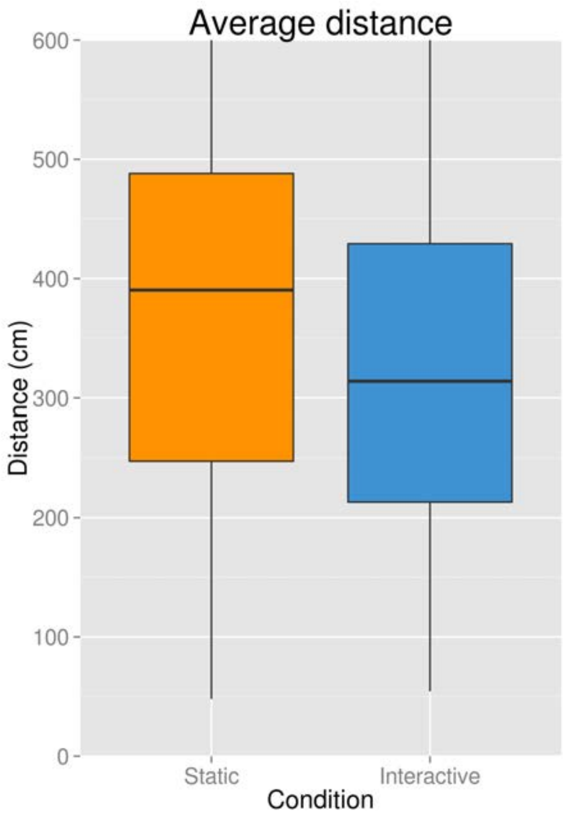



Figure 5.9: Average distance between all three participants

As the questionnaire on social presence revealed, participants showed higher levels of attentional engagement and indicated paying more attention towards each others' actions. In order to get a better understanding of how participants' proximity towards one another had an effect on these results, this was further analysed using Hall's interpretation of

| | Static | Interactive |
|---|---|---|
| **Intimate** (< 45 cm) | 0.06 ( 2.84) | 0.10 ( 1.47) |
| **Personal** (45 - 120 cm) | 13.15 (18.25) | 18.46 (12.10) |
| **Social** (120 - 360 cm) | 29.73 (18.25) | 36.70 (10.98) |
| **Public** (> 360 cm) | 49.80 (25.33) | 40.92 (12.27) |

Table 5.5: Normalised time participants spent in one of four zones. Values are represented as $\tilde{x}(\sigma)$.

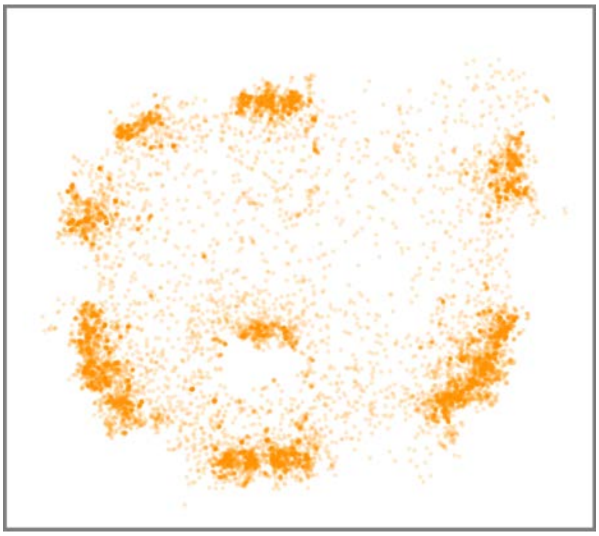
proxemic theory [35]. Distances between participants were categorised into four social zones, intimate (< 45 cm), personal (45 - 120 cm), social (120 - 360 cm), and public (> 360 cm), and the time participants spent in each one of these zones was calculated (see table 5.5).

One thing which becomes clear from looking at the different interaction zones is that participants spent most of their time in the outermost zone, the public zone. There appears to be some differences between the 'static' ($\mu = 52.14, \sigma = 25.33$) and 'interactive' ($\mu = 40.57, \sigma = 12.27$) conditions for this zone, however this difference was not significant $t(24) = 1.74, p = 0.28$. Participants also spent a notable amount of time in each others' social zone. However, after Holm-Bonferroni correction the difference between the 'static' ($\mu = 29.23, \sigma = 12.66$) condition, and the 'interactive' ($\mu = 37.53, \sigma = 10.98$) condition, appeared to be nonsignificant, $t(33) = -2.10, p = 0.17$. Also for the other two zones, intimate and personal, no differences were found.

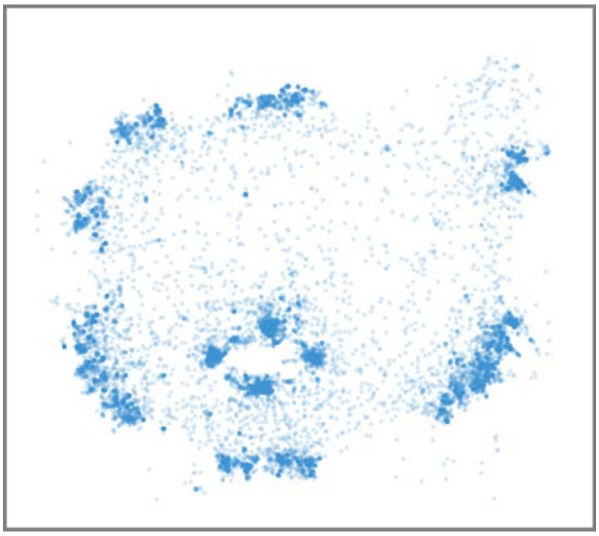
### Time spent at interactive tabletop

From the recorded tracking data participants' location was extracted. By combining all sessions for both the 'static' and 'interactive' conditions the locations where participant spent most of their time becomes visible (see figure 5.10).

One of the things which becomes clear is that in the 'interactive' condition the NFC pads along the four sides of the tabletop provided a designated location for participants to interact with the tabletop (see figure 5.10d). Whereas in the 'static' condition participants gathered around one side of the interactive tabletop (see figure 5.10c). Although participants visited



(a)



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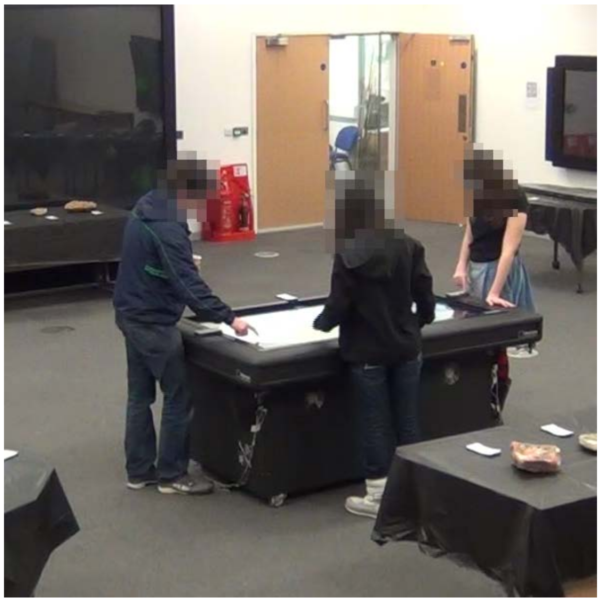
(c)



(d)

Figure 5.10: Combined participant locations during all 'static' (a), and 'interactive' (b) conditions. Participants gathered on one side of the tabletop during the 'static' condition (c), whereas during the 'interactive' condition NFC pads provided designated locations for tabletop interaction (d).

the interactive tabletop in both the 'static' and 'interactive' conditions, how often they returned to the interactive tabletop differed per condition (see figure 5.11). The results show that participants visited the interactive tabletop significantly more in the 'interactive' ($\tilde{x} = 4$) condition than in the 'static' ($\tilde{x} = 1$) condition, $Z = -4.18, p < 0.001$ (after Holm-Bonferroni correction for four comparisons).

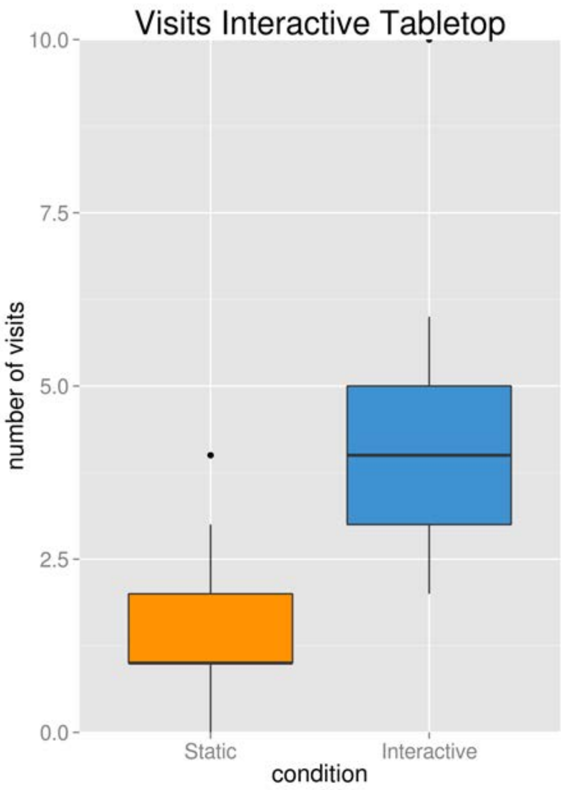



Figure 5.11: Number of visits to the interactive tabletop.

To get a better understanding of how participants spent their time at the interactive tabletop, figure 5.12 shows the normalised average time they spent at the interactive tabletop alone, in pairs, and as a trio. Values for the 'static' condition are presented on the left, and for the 'interactive' condition on the right with histograms indicating one, two, or three participants at the time.

Looking at the time participants spent at the interactive tabletop the results show that participants spent most of their time at the interactive tabletop alone, followed by pairs, and finally as a trio. This holds for both the 'static' and 'interactive' condition. Additionally, participants in the 'interactive' condition spent more time alone, as pairs, and as a trio at the interactive tabletop compared to the 'static' condition. The results show that participants in the 'interactive' condition spent around 25% of their visit interacting with the interactive tabletop alone, in contrast with nearly 8% of their visit in the 'static' condition. This difference was found to be significant, $t(7.41) = -5.89, p = 0.001$. Similar

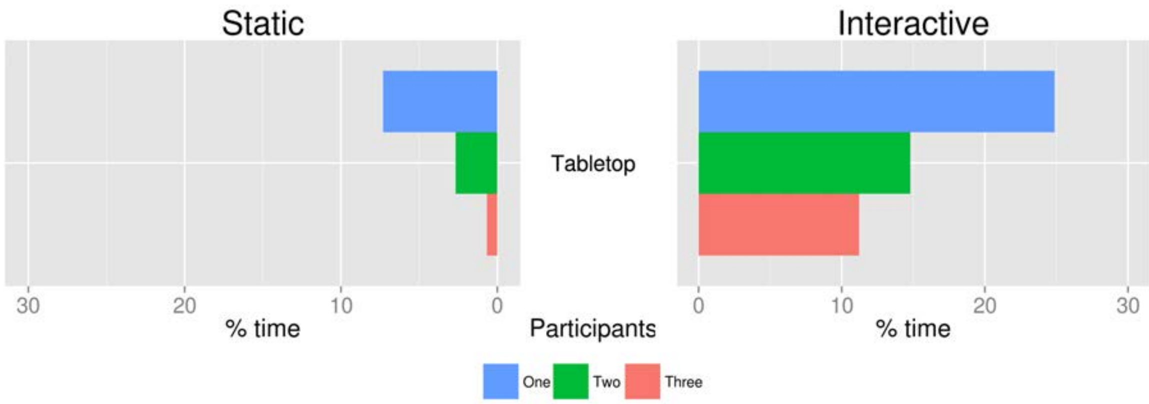



Figure 5.12: Average time participants spent at the interactive tabletop alone, in pairs, and as trio, with values for the 'static' condition on the left, and for the 'interactive' condition on the right.

results were found for spending time in pairs and as a trio at the interactive tabletop. These differences were also found to be significant, $t(6.38) = -3.27, p = 0.03$ for time spent in pairs, $Z = -2.22, p = 0.03$ for time spent as a trio (after Holm-Bonferroni correction for four comparisons).

### Time spent at artefacts

As the interactive tabletop provided an incentive for participants to collect artefacts and return to the interactive tabletop for further interaction, it was expected participants would visit artefacts more often during the 'interactive' condition. Results already showed the interactive tabletop was visited more frequently during the 'interactive' condition, however for the artefacts the opposite appeared to be true (see figure 5.13) as participants visited the artefacts more frequently in the 'static' ($\tilde{x} = 1.94$) condition than in the 'interactive' ($\tilde{x} = 1.56$) condition. After Holm-Bonferroni correction for four comparisons this difference was found to be significant, $Z = -3.10, p < 0.01$.

As for the interactive tabletop, the time participants spent at the artefacts alone, in pairs, and as a trio was also calculated (see figure 5.14) to examine differences between the two conditions. The figure shows the normalised average time for one, two, and three participants for all artefacts from the temporary museum exhibition. Values from the

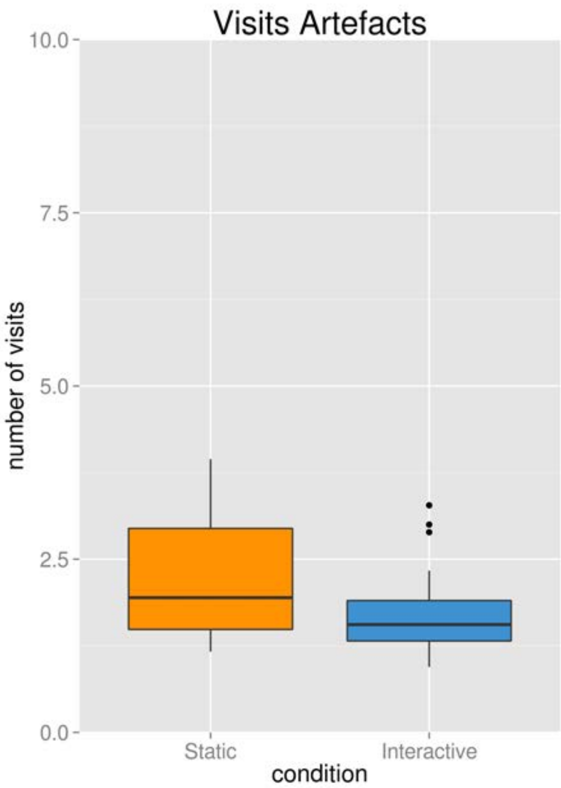



Figure 5.13: Number of visits to the artefacts.

'static' condition are on the left and for the 'interactive' condition on the right.

Looking at the time participants spent with the artefacts, one of the first observations is that participants spent more time at some artefacts than at others. For example, in the 'static' condition, participants spent on average 11% of their time interacting with the 'Quartz-Amethyst Geode' alone, compared to only just over 3% at the 'Gypsum'. Additionally, it is also clear participants spent most of their time interacting with the artefacts alone. Although this holds for both conditions, an independent samples t-test indicate that the time participants spent alone at the artefacts was significantly longer for the 'static' ($\mu = 6.28, \sigma = 2.25$) condition than for the 'interactive' ($\mu = 4.68, \sigma = 1.89$) condition, $t(23) = 4.81, p < 0.001$. Additionally, the results also show that participants spent more time interacting with the artefacts as a pair in the 'static' ($\tilde{x} = 0.47$) condition than the 'interactive' ($\tilde{x} = 0.12$) condition. This difference was also found to be significant, $Z = -3.13, p < 0.01$. As for the time interacting with the artefacts as a trio, the results show that for most artefacts participants hardly spent any time viewing it as a group.

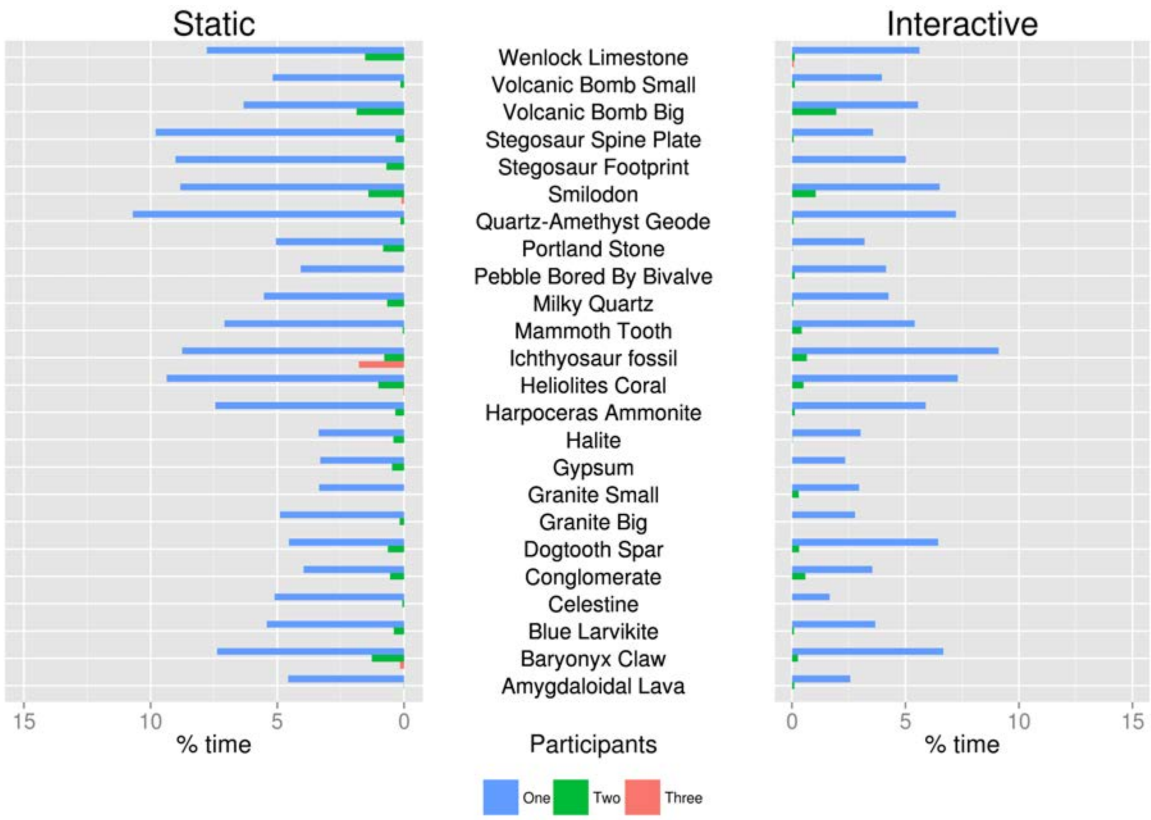



Figure 5.14: Average time participants spent at the artefacts alone, in pairs, and as trio, with values for the 'static' condition on the left, and for the 'interactive' condition on the right.

## 5.5 Discussion

The results of the experiment show high ratings for general positive affect and low ratings for general negative affect with no significant differences between the two conditions. This would suggest that the two conditions were almost identical in terms of affective response and any differences in participants' perception of social presence or cognitive absorption are not related to their affective responses.

It was expected that compared to the 'static' condition participants in the 'interactive' condition would spend more time around the interactive tabletop. This would result in an increased awareness of their group members and their actions, thereby rating higher in terms of social presence, in particular on the scales co-presence and attentional engagement. Although the result showed higher levels of co-presence and attentional engagement in the 'interactive' condition compared to the 'static' condition, no significant differences were found for these scales. Instead, for the co-presence scale participants rated their visit on average above 60% for both the 'static' and 'interactive' conditions. The questionnaire statements for the co-presence scale were directly related to participants' sense of location (e.g. "I often felt as if my friends and I were in the hall together") which could explain why no differences was found. With the temporary exhibition set up in a large hall, without any visual obstructions, participants were always able to see their friends, resulting in the high co-presence ratings for both the 'interactive' and 'static' conditions.

During the 'interactive' condition the average distance between the participants was significantly smaller compared to the 'static' condition. In addition, participants also spent more time at the interactive tabletop during the 'interactive' condition compared to the 'static' condition which might explain the increase of time spent in the social zone and decrease of time spent in the public zone. Although the smaller average distance between the participants and the increase in time spent at the interactive tabletop during the 'interactive' condition compared to the 'static' condition coincides with higher levels of attentional engagement, this difference was not significant. However, it might be a first indication that by allowing participants to continue their interaction with the artefacts on the interactive tabletop it could give them the opportunity, or forces them, to pay more attention to each others' actions.

Although it was expected that participants would be more involved with, or absorbed by, the exhibition during the 'interactive' condition compared to the 'static' condition no significant differences were found. This suggests that the combination of technologies did not offer more (or less) engagement for the participants, or that the application on the interactive tabletop offered little additional engagement. As participants did show high ratings for cognitive absorption (on average above 70%) it might have been a combination of the two. Although it was expected that the interactive tabletop would offer more engagement, the exhibition itself was already highly engaging through the use of smartphones, and by only showing the artefacts locations on the interactive tabletop interactions on the tabletop were limited.

Looking at the number of visits to, and the time spent at, the tabletop and artefacts some clear differences are visible between the ‘static’ and ‘interactive’ conditions. First of all the results showed a significant difference in visits to the interactive tabletop in the ‘interactive’ condition, suggesting participants found a purpose to revisit the interactive tabletop. In this case the interactive tabletop functioned as an interaction hub, drawing participants close, but also sending them on their way to collect other artefacts. However, the majority of their time participants spent visiting the interactive tabletop and the artefacts by themselves. Although participants did spend time in pairs at the interactive tabletop and with artefacts, only one artefact showed participants spending time as a group of three, the ‘Ichthyosaur’ fossil. Due to its size it was placed on a single table whereas other artefacts usually shared a table. The larger table on which the ‘Ichthyosaur’ fossil was placed, accommodated participants to view the fossil more easily together. This indicates that the setup and layout of artefacts will have to be carefully considered in order to accommodate group interaction and exploration.

Finally, by adding an interactive tabletop participants were drawn towards a common location, however at the same time away from the artefacts, and during the ‘interactive’ condition participants spent significantly less time at the original exhibition compared to the ‘static’ condition. As the interactive tabletop had an effect on the time visitors interact with the original artefacts and exhibition, museums should therefore carefully consider how an interactive tabletop is added to an exhibition, and how the original collection is incorporated.

Overall the results of this study support previous studies indicating interactive tabletops can engage participants and extend their interaction time when being alone, in pairs, or together as a group. However, during the study participants spent most of their time visiting artefacts or the tabletop alone. Results also suggest that when participants were able to continue their interaction with the artefacts on the interactive tabletop, they were drawn away from the actual museum artefacts. This suggests that museums should carefully consider the setup of their interactive tabletops and what they want visitors to take away from their visit.

As museum visits are also a social experience the research question "What are the effects of combining new technologies in a museum environment on group experiences?" is only partially answered. It would be interesting to run the experiment again with groups of friends to compare the influence of the used technologies between groups of individuals and groups of family or friends. Additionally, giving the intended purpose of overall project, it would be of interest to investigate changes in cognitive absorption with a more interactive setup (e.g. an interactive tabletop which offers a more complex interaction). However, increasing the complexity of the interactions with the interactive tabletop will most likely also increase the time participants spent at the interactive tabletop, strengthen effects found during this study. The next chapter will try to find a complete answer to the research question which was investigated in this chapter.

# Chapter 6
# Evaluating Group Composition

The study described in chapter 5 examined the effects of combining mobile and stationary technologies on groups of users. However, as museum visits are a social event the research question "What are the effects of combining new technologies in a museum environment on group experiences?", was only answered partially. Follow-up studies are needed to provide a complete overview. The study described in this chapter builds on the study from chapter 5 and investigates how the effects of combining these technologies differ for groups of family or friends.

## 6.1 Introduction

During the experiment in chapter 5 groups of three participants visited a temporary museum exhibition that was set up for this research. While visiting the exhibition they used a smartphone to interact with a number of artefacts, and in one condition also with an interactive tabletop. In the second condition the tabletop only showed a static image. The results of the experiment are in line with previous studies showing that an interactive tabletop increases interaction time [81]. However, the results also show that in return participants spent less time at the actual artefacts. This suggests that the design and information on the interactive tabletop will have to be carefully designed when incorporating in an existing exhibition.

As it was expected that results would be difficult to be observed when participants were familiar with each other, the groups of participants in chapter 5 consisted of people who did not know each other. However, as we “already know from basic surveys that visitors prefer to come in groups - particular family or friends” [11] and given the intended purpose of this thesis, it would be of interest to expand the experiment described in chapter 5 and compare the influence of mobile and stationary technologies between groups of individuals and friends or family. The purpose of the study described in this chapter is therefore twofold. First of all, to examine the influence of mobile and stationary technologies on groups of family or friends, and secondly to compare these findings with the experiment described in chapter 5.

## 6.2 Methodology

The study described in chapter 5 has shown that when interaction time with an interactive tabletop increased, in return interaction time with the artefacts decreased. This highlights an important design challenge and illustrates that museums should carefully consider how an interactive tabletop is added to an exhibition, and how the original collection is incorporated. As “visitors prefer to come in groups” [11] and chapters 4 and 5 focused on individuals and groups of individuals, this remains something to be investigated and forms the basis of the study described in this chapter which addresses the following research questions:

- What are the effects of combining mobile and stationary technologies in a museum environment on groups of family or friends in terms of social presence?
- What are the effects of combining mobile and stationary technologies in a museum environment on groups of family or friends in terms of cognitive absorption?

In order to find an answer to this research question the experimental setup of chapter 5 was used with a different composition of participants. To test a number of hypotheses an experiment was designed in which groups of family or friends could interact and engage with museum artefacts using novel interaction modalities combining mobile and stationary technologies. As the experimental setup remains the same as in the study described in chapter 5 this also allows for a close examination of differences in social presence and cognitive absorption between the two different groups. This resulted in two more research questions which were also examined during this study.

- What are the effects of group composition on group experiences in terms of social presence?
- What are the effects of group composition on group experiences in terms of cognitive absorption?

Using the questionnaires from the experiment in chapter 5 participants' perception of social presence and cognitive absorption could be measured, evaluated, analysed and compared.

## 6.3 Experiment

In order to answer the first two research questions of this study, "What are the effects of combining mobile and stationary technologies in a museum environment on groups of family or friends in terms of social presence?" and "What are the effects of combining mobile and stationary technologies in a museum environment on groups of family or friends in terms of cognitive absorption?", the experimental setup as described in 5 was used with a different set of participants. This also allowed for collecting data to answer the latter two research questions, "What are the effects of group composition on group experiences in terms of social presence?" and "What are the effects of group composition on group experiences in terms of cognitive absorption?". The experiment design will be further described in this section, along with how the data was analysed and the participants who took part in the study.

### 6.3.1 Participants

During the study 42 participants (17 female and 25 male), aged between 13 and 47 ($\mu = 23.86, \sigma = 6.66$) took part in the experiment. Participants ranged from IT and non-IT related students to full-time staff from departments across the university who invited family or friends to join them. Out of the 42 participants 40 described themselves as at least a 'frequent computer user', the other two indicated not to 'use computers very often'. Just over half of the participants (28 out of 42) had visited a museum within the last 3 months, and indicated visiting museums with friends (30 out of 42), family (20 out of 42), partner (9 out of 42), and alone (12 out of 42). Before the experiment all participants, or in case of children their caretaker, signed an informed consent form and they were paid according to institution's regulations.

### 6.3.2 Setup

For the experiment in this study the same experimental setup of chapter 5 was used. Twenty-four museum artefacts[1], including rocks, minerals and fossils provided by the Lapworth Museum of Geology, were placed on tables around an interactive tabletop at a temporary museum exhibition (see figure 6.1).

Similar to the experimental setup in chapter 5 participants were given an NFC enabled smartphone to interact with the artefacts and the interactive tabletop. Both the Android application on the smartphones and the application on the interactive tabletop were kept the same and the NFC pads from chapter 5 were placed next to the artefacts and interactive tabletop (see figure 6.2).

[1]Besides the Smilodon skull the same artefacts were used as the experiment from chapter 5. The Smilodon skull was replaced with a Gastropod.

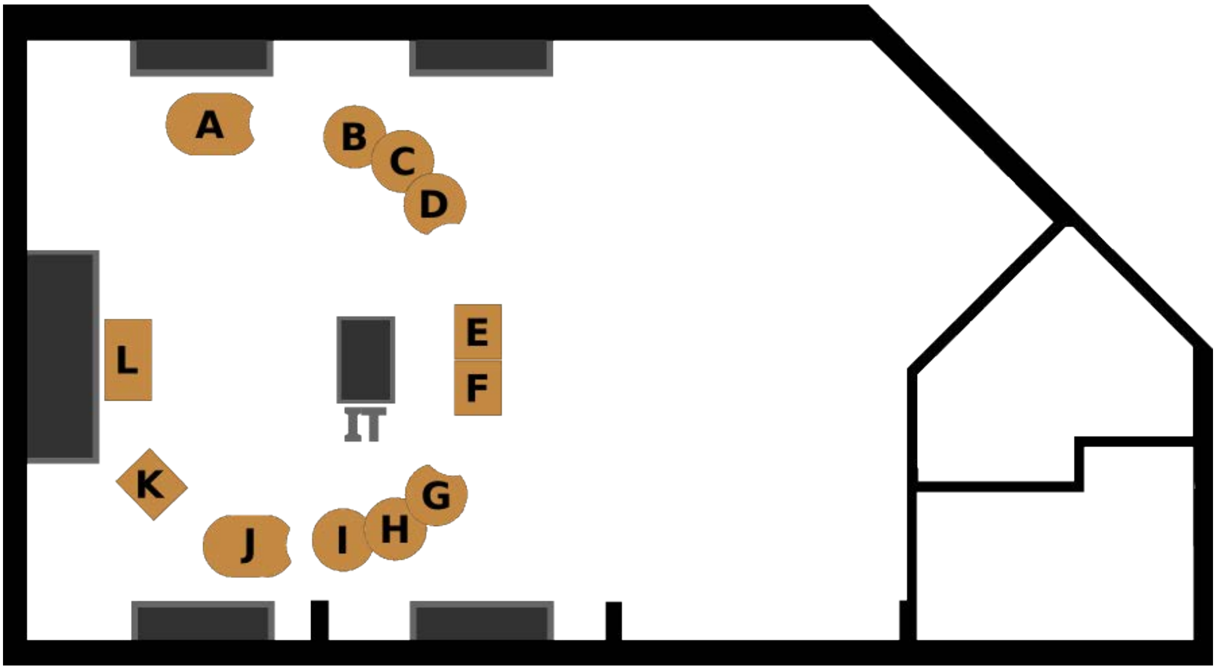



Figure 6.1: Layout of the Hall with the tables for the museum artefacts (A-L), and the interactive tabletop (IT)

Figure 6.2: Interactive tabletop with four NFC pads at the centre of each side for user interaction

| Group | Age | Gender | Mother Tongue | Acquaintanceship |
|---|---|---|---|---|
| **1** | 29.33 ( 3.21) | 2F / 1M | 3 German | Friends |
| **2** | 25.00 ( 2.65) | 1F / 2M | 1 Dutch<br>2 English | Friends |
| **3** | 25.33 ( 7.09) | 2F / 1M | 2 German<br>1 Lithuanian | Partners and friend |
| **4** | 22.67 ( 2.31) | 1F / 2M | 2 Chinese<br>1 French | Friends |
| **5** | 18.33 ( 0.58) | 1F / 2M | 3 English | Friends |
| **6** | 24.67 (19.35) | 1F / 2M | 3 English | Mother and kids |
| **7** | 19.33 ( 0.58) | 1F / 2M | 3 English | Partners and friend |
| **8** | 18.33 ( 0.58) | 3M | 2 English<br>1 Romanian | Friends |
| **9** | 23.00 ( 0.00) | 3M | 1 Chinese<br>2 English | Friends |
| **10** | 27.00 ( 3.46) | 3M | 2 English<br>1 Spanish | Friends |
| **11** | 34.33 ( 1.53) | 3F | 3 English | Colleagues |
| **12** | 19.00 ( 0.00) | 3M | 3 English | Friends |
| **13** | 26.67 ( 5.69) | 3F | 1 Chinese<br>1 English<br>1 Swedish | Friends |
| **14** | 21.00 ( 0.00) | 2F / 1M | 3 Chinese | Friends |

Table 6.1: Compositions of the groups, showing age (represented as $\mu(\sigma)$), gender (represented as Female / Male), mother tongue and acquaintanceship.

During the experiment groups of three participants visited the temporary museum exhibition in sessions up to 15 minutes during which they could interact with the artefacts and interactive tabletop. In contrast to the experiment in chapter 5 where groups of individuals took part in the study, for this experiment groups of three family members or friends were invited to take part in the study (see table 6.1). Upon arrival the group was given an information sheet about the study (see appendix F), a short introduction on the procedure of the experiment and were instructed on the use of the smartphone and NFC pads. Each participant was then given a smartphone and glasses with tracking markers after which the group was directed to the temporary museum exhibition. Visits lasted between 10 to 15 minutes after which they were collected and were asked a few questions about the temporary museum exhibition prior to completing two more questionnaires.

As with the experiment in chapter 5 the experiment consists of two conditions, 'interactive' and 'static'. To avoid confounding variables such as familiarity with the exhibition, or technology, a between subjects design was used and groups were randomly assigned to one of the two conditions. Additionally, only participants who did not take part in any of the previous studies were allowed to participate. In the first condition (i.e. the 'interactive' condition) participants could interact with both the artefacts and the interactive tabletop through their smartphone. In the second condition (i.e. the 'static' condition) the NFC pads around the interactive tabletop were removed and participants could only interact with the artefacts through their smartphone.

### 6.3.3 Data Acquisition

The protocol of the experiment is similar to that of the experiment described in chapter 5. Before taking part in the study participants were asked to complete an online demographic questionnaire (see appendix G) either at home or upon arrival. Additionally, participants were asked to complete two more online questionnaires (in random order) immediately after their visit to the temporary museum exhibition. In order to measure participants' perception of social presence, the 'Networked Minds Social Presence Inventory' was used (see appendix H). For measuring participants' engagement with the temporary museum exhibition, Agarwal's *et al.* questionnaire [1] on cognitive absorption was used (see appendix I). The PANAS-X questionnaire which was used during the experiment described in chapter 5 already illustrated that there were no significant differences in affective response which could explain any of the differences in social presence and cognitive absorption. The PANAS-X was therefore omitted from this experiment. As during the experiment described in chapter 5 participants' movements were tracked within the temporary museum environment using glasses with tracking markers. Additionally, a video camera was mounted on a tripod providing a bird's-eye view of the temporary exhibition and recorded participants interactions during their visit. This would allow for validating the tracking data as well as investigating abnormalities in the data.

### Social Presence

In line with the experiment described in chapter 5 it was expected that the interactive tabletop would draw participants closer together over a longer period.

Although no significant differences were found for the factors co-presence and attentional engagement during the previous experiment, a smaller average distance between the participants and an increase in time spent at the interactive tabletop coincided with higher levels of attentional engagement during the 'interactive' condition compared to the 'static' condition. This might be a first indication that by allowing participants to continue their interaction with the artefacts on an interactive tabletop it could give them the opportunity, or forces them, to pay more attention to each others' actions. For this experiment it is expected that the differences in attentional engagement become more apparent between the 'static' and 'interactive' conditions. As results from the previous experiment suggest that the difference in attentional engagement is an effect of the interactive tabletop, and since that besides group composition the experiment remains the same, no difference in attentional engagement is expected between the two experiments.

In the experiment described in chapter 5 it was assumed that crossed social boundaries between groups of friends or family could conceal the socialising potential of the interactive tabletop. Therefore, groups were composed of individuals and it was expected that the interactive tabletop would result in higher levels of co-presence for the 'interactive' condition compared to the 'static' condition. Results of the experiment showed no difference in levels of co-presence between the two conditions and similar results are expected for this experiment. However, as participants in this experiment are familiar with each other, it is expected that they pay more attention to each others' presence which will result in higher levels of co-presence for this experiment compared to the previous experiment.

Additionally, "individuals may be less likely to display behaviors that are displayed by out-group members in an attempt to avoid affiliation, or association, with those individuals" [61] and they are more likely to mimic behaviour of others whom they feel associated with [95]. It is therefore expected that groups of family or friends will show higher levels of behavioural interdependence for this experiment compared to the experiment described in chapter 5. No difference in levels of behavioural interdependence is expected between the ‘static’ and ‘interactive’ conditions for this experiment. For the other two factors (i.e. emotional contagion and comprehension) no differences were expected between the conditions or the experiments.

#### Cognitive Absorption

In terms of cognitive absorption one of the hypotheses in the study described in chapter 5 suggested that the interactive tabletop would offer a more engaging experience. This would result in higher ratings in the factors temporal dissociation and focused immersion. However, during the analysis no significant differences were found. Possibly the exhibition itself was already highly engaging through the use of smartphones. Additionally, by only showing the artefacts locations on the interactive tabletop, interactions on the tabletop were limited. In order to compare the results from the experiment described in chapter 5 with the results from this experiment only group compositions were adjusted while the rest of the experimental setup remained the same. Therefore, no significant differences were expected for the factors of cognitive absorption between the conditions or the experiments.

#### User Tracking

Analysis of the experiment described in chapter 5 showed that some artefacts were more popular than others and that participants spent more time interacting with these artefacts compared to others. This was also true for the time participants spent at the interactive tabletop which was longer in the ‘interactive’ condition compared to the ‘static’ condition. In return, participants also spent less time at the actual exhibition and its artefacts. In terms of time spent at the interactive tabletop and artefacts, similar results are expected for this experiment. More specifically, it is expected that participants spend more time at the interactive tabletop and less time at the artefacts in the ‘interactive’ condition compared to the ‘static’ condition. As the previous experiment suggests this is an effect of the interactive tabletop, it is not expected that group composition will have an effect on time spent at the interactive tabletop or artefacts.

In addition to analysing the time spent at the total interactive tabletop or artefacts the experiment described in chapter 5 also analysed the time participants spent alone, in pairs and as a trio interacting with the artefacts of interactive tabletop. Overall the times spent alone, in pairs and as a trio at the tabletop were different between the 'static' and 'interactive' conditions. Although similar differences are expected for this experiment between the 'static' and 'interactive' conditions, it is not expected that group composition has an effect on the times spent alone, in pairs and as a trio at the tabletop. However, it is expected that group composition has an effect on the time participants spent in pairs or as a trio at the artefacts.

The experiment described in chapter 5 also revealed a smaller average distance between group members in the 'interactive' condition compared to the 'static' condition. However, in contrast to the previous experiment, participants in this experiment know each other. It is therefore expected that for this experiment the average distance between participants for the 'static' and 'interactive' condition will not show any difference. However, it is expected that group composition will have an effect on the average distance between group members as they will spend more time close together. Additionally, the previous experiment compared participants proximity towards one another using Hall's interpretation of proxemic theory [35]. In line with the expectation that group composition will have an effect on the average distance between group members, it is also expected that group composition will have an effect on the time participants spend in one of Hall's four social zones. In particular it is expected that groups of friends or family will spend more time in the intimate and personal zones compared to groups of individuals. Additionally, it is expected that groups of friends or family explore more parts of the exhibition together and will therefore spend less time in the public zone compared to groups of individuals. Finally, in line with the results from chapter 5 it is expected that since the time spent at the interactive tabletop will be longer in the 'interactive' condition compared to the 'static' condition, participants will also spend more time in the social zone during the 'interactive' condition compared to the 'static' condition.

### 6.3.4 Analysis

After the experiments ratings were obtained for the five constructs of social presence and the five factors of cognitive absorption. All ratings from the questionnaires were normalised and extreme values were adjusted to 3 standard deviations. Then, overall differences in perceived levels of social presence and cognitive absorption were analysed using a 2(interaction: 'static' vs. 'interactive') x 2(group: 'unknown' vs. 'familiar') multivariate analysis of variance (MANOVA). When overall analysis indicated a presence of significant differences, these were further evaluated using independent ANOVA analysis. The independent ANOVAs were corrected using the Holm-Bonferroni correction with a combined significance of $p \leq 0.05$ for each of the different measurements. In case of a significant difference, a Tukey's HSD test was performed for post-hoc analysis to assess where the differences occurred.

For the quantitative analysis, tracking data was processed using the same method as described in the analysis section of chapter 5. Tracking data was then pre-processed to extract the distance and time participants spent together, the time participants spent at the interactive tabletop, and the time participants spent at the artefacts. These were then analysed using 2(interaction: 'static' vs. 'interactive') x 2(group: 'unknown' vs. 'familiar') independent ANOVAs with Holm-Bonferroni correction. In case of a significant interaction between factors, Tukeys HSD tests were performed for post-hoc analysis to assess where the differences occurred.

## 6.4 Results

The following section describes the results of the analysis of the questionnaires and the quantitative data. Results are then related to different perspectives to provide a complete overview.

### 6.4.1 Questionnaires

#### Social Presence

First, the results of the 'Networked Minds Social Presence Inventory' (see table 6.2) were analysed. The overall differences in perceived levels of social presence were analysed using a 2(interaction: 'static' vs. 'interactive') x 2(group: 'unknown' vs. 'familiar') multivariate analysis of variance (MANOVA). This analysis showed no significant main effect for the condition factor, $F(5, 70) = 0.72, p = 0.61; Wilks'\lambda = 0.95$, and no significant main effect for the experiment factor, $F(5, 70) = 1.56, p = 0.18; Wilks'\lambda = 0.90$. The interaction between the factors interaction and group was however, significant, $F(5, 70) = 3.54, p < 0.01; Wilks'\lambda = 0.80$. The interaction effects between the factors interaction and group were therefore further analysed for the five constructs of social presence (i.e. co-presence, attentional engagement, emotional contagion, comprehension and behavioural interdependence).

| | Static | Interactive |
|---|---|---|
| **Co-presence** | 75.00 (18.37) | 73.21 ( 9.59) |
| **Attentional Engagement** | 61.90 (11.98) | 57.15 (13.59) |
| **Emotional Contagion** | 51.79 (14.63) | 55.36 (11.56) |
| **Comprehension** | 71.43 (11.94) | 73.81 (10.13) |
| **Behavioural Interdependence** | 64.29 (14.80) | 69.05 (11.56) |

Table 6.2: Normalised ratings for the five factors of social presence. Values are represented as $\tilde{x}(\sigma)$.

In line with the results of the experiment described in chapter 5 there was no difference expected in perceived levels of co-presence between the 'interactive' and 'static' conditions.

However, as participants in the experiment were familiar with each other there was a difference expected in perceived levels of co-presence between the two experiments. As the overall analysis only revealed a significant interaction between interaction and group, only this was analysed using an independent ANOVA (with Holm-Bonferroni correction for five comparisons). This analysis revealed no significant interaction between the factors interaction and group, $F(1, 74) = 0.48, p = 0.64$.

Following the results from the experiment described in chapter 5 it was expected that differences in perceived levels attentional engagement would become more apparent between the 'static' and 'interactive' conditions. As results from the previous experiment suggested that the difference in attentional engagement was an effect of the interactive tabletop, and since that besides group composition the experiment remained the same, no difference was expected between the two experiments. As with co-presence, only the interaction effect between the factors interaction and group were analysed using an independent ANOVA with Holm-Bonferroni correction for multiple comparisons. This analysis revealed a significant interaction between the factors interaction and group, $F(1, 74) = 7.40, p < 0.04$. Post-hoc Tukey's HSD tests showed statistical significance between groups of family or friends during the 'static' condition ($\mu = 63.49, \sigma = 11.98$) and the groups of individuals during the 'static' condition ($\mu = 48.94, \sigma = 16.28$). Other comparisons of the Tukey's HSD tests were not significant.

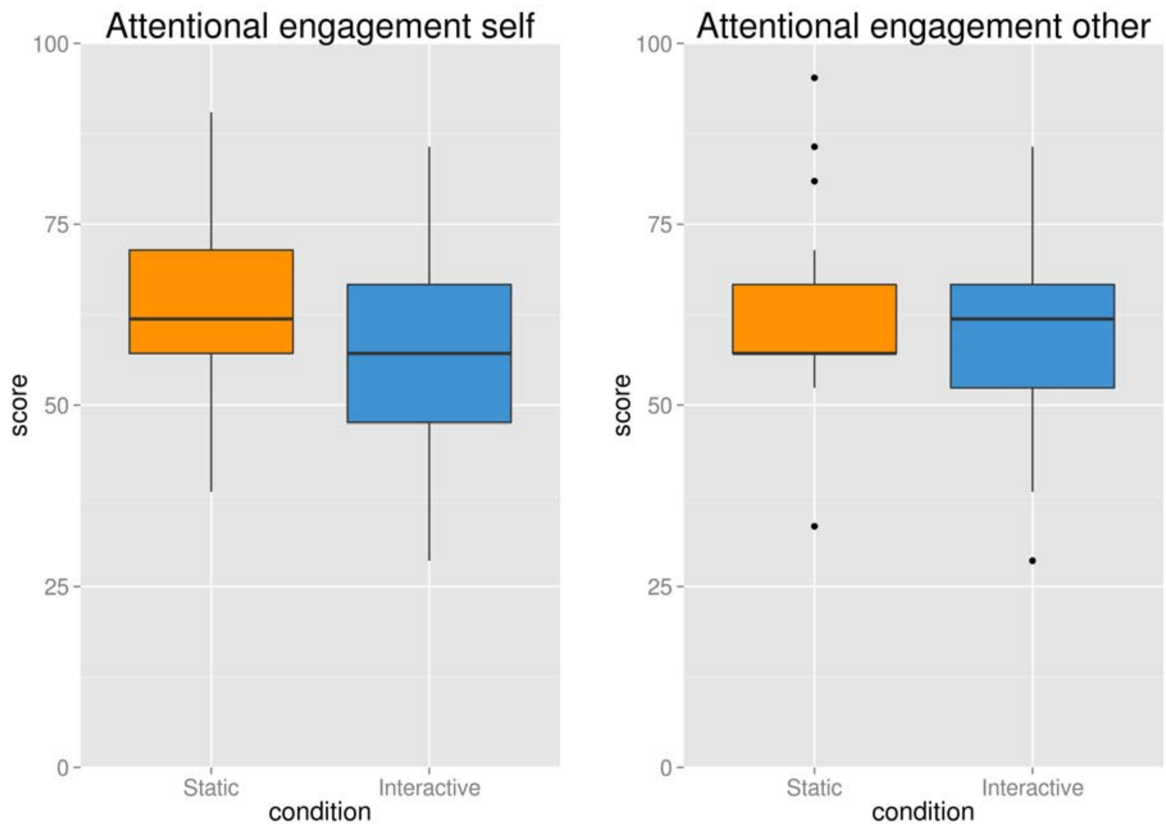
The only other factor of social presence for which a difference was expected is behavioural interdependence. As people are more easily influenced by actions of friends or family it was expected that group composition would have an effect on perceived levels of behavioural interdependence. As with the co-presence and attentional engagement factors also here only the interaction effect was analysed. However, after Holm-Bonferroni correction the analysis showed no significant interaction between the factors interaction and group, $F(1, 74) = 4.75, p = 0.13$. For the other two factors of social presence (i.e. emotional contagion, comprehension) no differences were expected. For emotional contagion the analysis of the interaction effect between the factors interaction and group showed no significant difference, $F(1,74) = 0.99, p = 0.64$. Similarly, analysing comprehension showed no significant interaction effect between the factors interaction and group, $F(1,74) = 2.80, p = 0.30$.

As the 'Networked Minds Social Presence Inventory' also allows to separate participants' perception of themselves and their perception of their group members, the sub scales of attentional engagement were further analysed (see figure 6.3). Again the perceived levels of attentional engagement were first analysed using a 2x2 multivariate analysis of variance (MANOVA). This analysis showed no significant main effect for the factor condition or experiment, $F(2,73) = 0.39, p = 0.68; Wilks'\lambda = 0.99$ and $F(2,73) = 1.99, p = 0.14; Wilks'\lambda = 0.95$ respectively. However, the interaction between the factors interaction and group was found significant, $F(2,73) = 4.75, p = 0.01; Wilks'\lambda = 0.88$. The interaction effects between the sub scales of attentional engagement were therefore further analysed using independent ANOVAs with Holm-Bonferroni correction for multiple comparisons.

When looking at the levels of attention participants paid to others, analysis of the interaction between the factors interaction and group showed a significant difference, $F(1,74) = 9.49, p < 0.01$ (with Holm-Bonferroni correction for two comparisons). Post-hoc Tukey's HSD tests showed statistical significance during the 'static' condition between groups of family or friends ($\mu = 63.71, \sigma = 13.00$) and groups of individuals ($\mu = 48.41, \sigma = 17.30$), ($p < 0.05$) and a statistical significant difference between the 'static' condition ($\mu = 48.41, \sigma = 17.30$) and the 'interactive' condition ($\mu = 63.23, \sigma = 17.12$) for groups of individuals ($p < 0.05$). Other comparisons were not significant. For the levels of perceived attention others paid to participants, analysis showed no significant interaction effect, $F(1,74) = 3.83, p = 0.05$.

### Cognitive Absorption

Finally the results of the Cognitive Absorption questionnaire were analysed (see table 6.3). Following the results from the study described in chapter 5 it was expected that




(a) (b)

Figure 6.3: Normalised ratings for participants' perception of attentional engagement of self (a), and of others (b).

participants would not be more absorbed in, or involved with, the temporary exhibition in the 'interactive' condition compared to the 'static' condition. Neither were there any differences expected between the two experiments.

As the overall cognitive absorption was constructed from the five factors of cognitive absorption it was investigated seperately using a two-way independent ANOVA. This analysis showed no significant main effect between the 'static' and 'interactive' conditions, $F(1, 74) = 0.07, p = 0.79$ and no significant main effect between the two experiments, $F(1, 74) = 2.03, p = 0.16$. Also, the interaction between the factors interaction and group composition was not significant, $F(1, 74) = 0.28, p = 0.60$.

The five factors of cognitive absorption were analysed using a 2x2 multivariate analysis of variance (MANOVA) to determine if there were any significant differences worth

| | Static | Interactive |
|---|---|---|
| **Cognitive Absorption** | 72.86 ( 9.95) | 77.14 (13.13) |
| **Temporal Dissociation** | 77.14 (15.36) | 77.14 (18.39) |
| **Focused Immersion** | 65.71 (13.26) | 68.57 (12.86) |
| **Heightened Enjoyment** | 82.14 (11.98) | 82.14 (17.66) |
| **Control** | 57.14 ( 7.75) | 61.90 ( 8.84) |
| **Curiosity** | 85.71 (14.39) | 80.95 (19.82) |

Table 6.3: Normalised ratings for cognitive absorption and its five factors. Values are represented as $\tilde{x}(\sigma)$.

investigating. Although no differences were expected, the analysis showed a significant main effect for the experiment factor, $F(5,70) = 9.71, p < 0.001; Wilks'\lambda = 0.59$. For the main effect of the condition factor no significant difference was found , $F(5,70) = 1.64, p = 0.16; Wilks'\lambda = 0.89$. There was also no significant difference for the interaction between the factors interaction and group, $F(5,70) = 0.16, p = 0.98; Wilks'\lambda = 0.99$.

As the overall analysis of the five factors of cognitive absorption indicated a significant main effect for the experiment factor, the five factors were further analysed using independent ANOVA with Holm-Bonferroni correction for five comparisons. Only for the control factor did this result in a significant difference between the two experiments, $F(1,74) = 45.57, p < 0.001$. For the temporal dissociation factor the analysis showed no significant main effect between the two experiments, $F(1,74) = 0.01, p = 1.00$. Similar results were visible for the focused immersion factor where the analysis showed no significant main effect between the two experiments, $F(1,74) = 0.03, p = 1.00$. The analysis of the heightened enjoyment factor also showed no significant main effect between the two experiments, $F(1,74) = 0.10, p = 1.00$. Also, for the last factor, curiosity, analysis showed no significant main effect between the two experiments, $F(1,74) = 1.42, p = 0.95$.

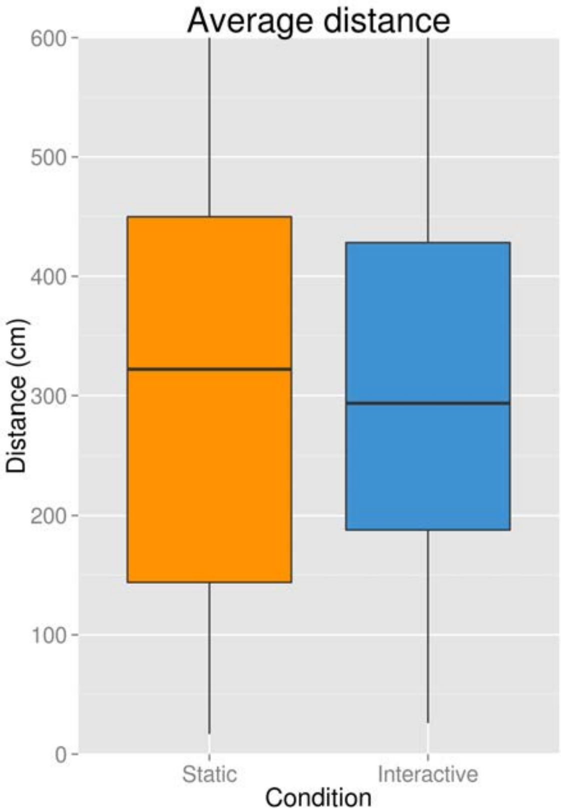



Figure 6.4: Average distance between the three participants for the two conditions

### 6.4.2 User Tracking

#### Time spent together

As with the experiment described in chapter 5 the average distance between the three participants was calculated (see figure 6.4). In contrast to the previous experiment it was expected that there would be no difference between the 'static' and 'interactive' condition for this experiment but that group composition would have an effect on the average distance between participants.

After Holm-Bonferroni correction for fifteen comparisons, a two-way independent ANOVA revealed a significant main effect for the condition factor, $F(1, 19523) = 258.23, p < 0.001$, and a significant main effect for the experiment factor, $F(1, 19523) = 115.44, p < 0.001$. In addition to the significant main effects the interaction between the factors interaction and group composition was also significant, $F(1, 19523) = 95.18, p < 0.001$.

| | Static | Interactive |
|---|---|---|
| **Intimate** (< 45 cm) | 2.19 ( 6.02) | 1.24 ( 3.59) |
| **Personal** (45 - 120 cm) | 19.83 (15.56) | 17.78 (12.89) |
| **Social** (120 - 360 cm) | 31.60 (11.07) | 43.06 (11.39) |
| **Public** (> 360 cm) | 37.32 (25.87) | 37.83 (17.93) |

Table 6.4: Normalised time participants spent in one of four zones. Values are represented as $\tilde{x}(\sigma)$.

Post-hoc Tukey's HSD tests showed statistical significance between groups of family or friends and groups of individuals for the 'static' condition ($p < 0.001$), between the 'static' and 'interactive' conditions for groups of individuals ($p < 0.001$), between groups of family or friends and groups of individuals for the 'interactive' condition ($p < 0.001$) but not between the 'static' and 'interactive' conditions for groups family or friends ($p = 0.53$).

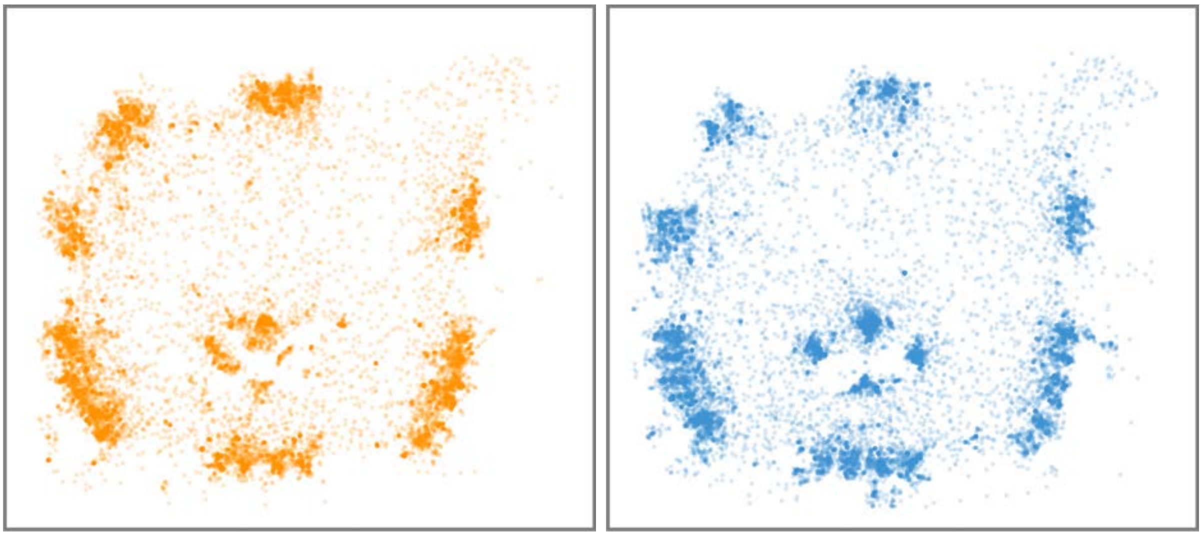
Following the procedure of the experiment described in chapter 5 distances between participants were categorised into four social zones (i.e. intimate, personal, social and public) and the time participants spent in each one of these zones was calculated (see table 6.4). Looking at the results it becomes clear that for the 'interactive' condition participants spent most of their time in the social zone whereas in the 'static' condition participants spent most of their time in the public zone.

It was expected that group composition would have an effect on the time participants spend in one of these four social zones. More specifically that groups of friends or family would spend more time in the intimate and personal zones compared to groups of individuals. However, for time spent in the intimate zone the analysis showed no significant main effect between the two experiments, $F(1, 74) = 6.55, p = 0.14$ (after Holm-Bonferroni correction for multiple comparisons) and no significant main effect between the 'static' and 'interactive' conditions, $F(1, 74) = 0.62, p = 1.00$. The interaction between the factors interaction and group composition was also not significant, $F(1, 74) = 0.13, p = 1.00$. In addition, also for the time spent in the personal zone the analysis showed no significant main effect between the 'static' and 'interactive' conditions, $F(1, 74) = 0.04, p = 1.00$ and no significant main effect between the two experiments, $F(1, 74) = 0.83, p = 1.00$. Also, the interaction between the factors interaction and group composition was not significant, $F(1, 74) = 1.44, p = 1.00$.

Additionally, it was expected that participants would spend more time in the social zone during the ‘interactive’ condition compared to the ‘static’ condition. After Holm-Bonferroni correction the analysis showed a significant main effect between the ‘static’ and ‘interactive’ conditions, $F(1, 74) = 10.77, p = 0.02$. No significant main effect was found between the two experiments, $F(1, 74) = 2.27, p = 1.00$, nor was the interaction between the factors interaction and group composition significant, $F(1, 74) = 0.01, p = 1.00$. As it was expected that the average distance between groups of family or friends would be smaller compared to the average distance between groups of individuals it was also expected that group composition would have an effect on the time spent in the public zone. However, after correction the analysis revealed no significant main effect between the two experiments, $F(1, 74) = 4.15, p < 0.45$ and no significant main effect between the ‘static’ and ‘interactive’ conditions, $F(1, 74) = 2.15, p = 1.00$. Also, the interaction between the factors interaction and group composition was not significant, $F(1, 74) = 0.76, p = 1.00$.

#### Time spent at interactive tabletop

From the recorded tracking data participants’ movements were extracted for each sessions. Combining these locations for both the ‘static’ and the ‘interactive’ conditions gives an overview of the locations where participant spent most of their time (see figure 6.5).



(a) (b)

Figure 6.5: Participants' locations during the 'static' (a), and 'interactive' (b) conditions.

In line with the results from the experiment described in chapter 5 the overview in figure 6.5 illustrates that during the 'interactive' condition the NFC pads along the four sides of the interactive tabletop provided a designated location for participants to interact with the tabletop. However, in contrast to the previous experiment participants also seem to be standing along multiple sides of the interactive tabletop in the 'static' condition. In terms of visits to the interactive tabletop (see figure 6.6) it was expected that there would be a difference between the 'static' and 'interactive' conditions. After Holm-Bonferroni correction for twelve comparisons a two-way independent ANOVA indicated a significant main effect between the 'static' and 'interactive' conditions, $F(1, 74) = 34.63, p < 0.001$ and no significant main effect between the two experiments, $F(1, 74) = 1.15, p = 1.00$. The interaction between the factors interaction and group composition was not significant, $F(1, 74) = 0.21, p = 1.00$.

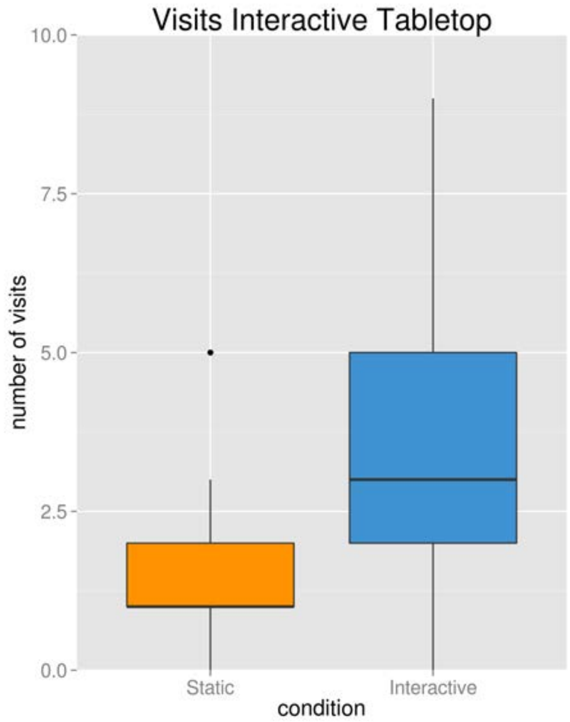



Figure 6.6: Number of visits to the interactive tabletop.

As the results from the experiment described in chapter 5 illustrates, the time participants spent with others at the interactive tabletop differs per condition (see figure 5.12). Figure 6.7 clearly shows that participants spent more time alone and in pairs at the interactive tabletop during the 'interactive' condition compared to the 'static' condition. For the time spent alone at the interactive tabletop the analysis revealed a significant main effect between the 'static' and 'interactive' conditions, $F(1,22) = 50.83, p < 0.001$ and no significant main effect between the two experiments, $F(1,22) = 2.52, p = 1.00$. Also, the interaction between the factors interaction and group composition was not significant, $F(1,22) < 0.01, p = 1.00$. The time participants spent in pairs at the interactive tabletop showed similar results where the analysis revealed a significant main effect between the 'static' and 'interactive' conditions, $F(1,22) = 13.28, p = 0.01$ (after Holm-Bonferroni correction for twelve comparisons) and no significant main effect between the two experiments, $F(1,22) = 1.89, p = 1.00$. Also, the interaction between the factors interaction and group composition was not significant, $F(1,22) = 1.64, p = 1.00$.

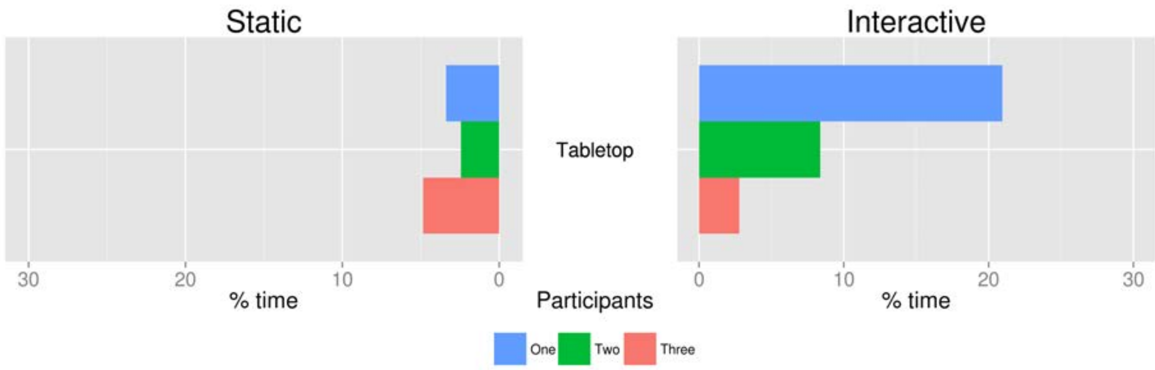



Figure 6.7: Average time participants spent at the interactive tabletop alone, in pairs, and as trio, with values for the 'static' condition on the left, and for the 'interactive' condition on the right.

Figure 6.7 also shows that during the 'static' condition participants spent more time at the tabletop as a trio compared to the static condition which is also in contrast to the groups of individuals. A two-way independent ANOVA showed no significant main effect between the 'static' and 'interactive' conditions, $F(1, 22) = 1.69, p = 1.00$ and no significant main effect between the two experiments, $F(1, 22) = 0.54, p = 1.00$. Also the interaction between the factors interaction and group composition was not significant, $F(1, 22) = 4.74, p = 0.36$.

#### Time spent at artefacts

Results have already illustrated that participants paid more visits to the tabletop in the 'interactive' condition compared to the 'static' condition. During the experiment described in chapter 5 similar results were observed however, in return participants paid fewer visits to the actual museum artefacts. Looking at the number of visits to the artefact (see figure 6.8) this effect also seems to appear during this experiment. After Holm-Bonferroni correction for twelve comparisons, a two-way repeated-measures ANOVA showed a significant main effect between the 'static' and 'interactive' conditions, $F(1, 22) = 17.66, p < 0.001$ but no significant main effect between the two experiments, $F(1, 22) = 7.08, p = 0.11$. The interaction between the factors interaction and group composition was not significant, $F(1, 22) = 1.42, p = 0.80$.

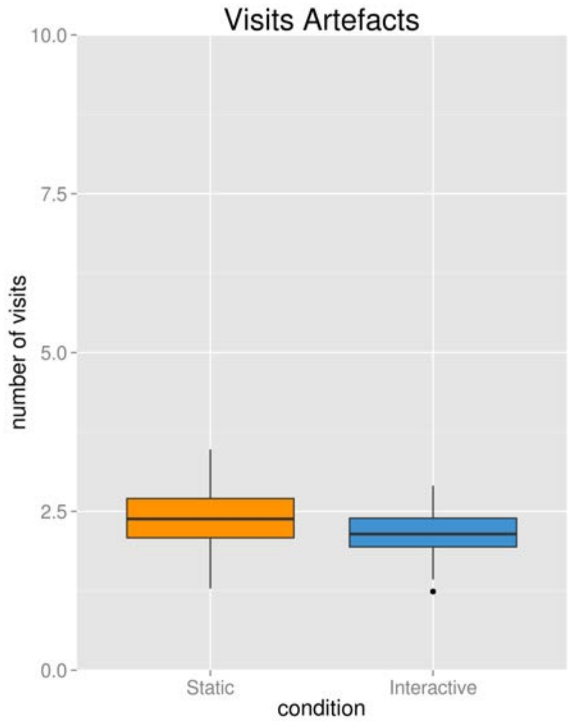



Figure 6.8: Number of visits to the artefacts.

As for the interactive tabletop the times participants spent at the artefacts alone, in pairs, and as a trio were calculated (see figure 6.9). When comparing the figure with figure 5.14 it seems that groups of family or friends spent more time as a trio interacting with museum artefacts compared to groups of individuals. A two-way repeated-measures ANOVA showed that this difference was significant and revealed a significant main effect between the two experiments, $F(1, 22) = 11.22, p = 0.02$. There was no significant main effect between the 'static' and 'interactive' conditions, $F(1, 22) = 2.44, p = 0.80$, nor was the interaction between the factors interaction and group composition significant, $F(1, 22) = 0.35, p = 1.00$.

Further investigation also showed differences between the time participants spent interacting with museum artefacts as a pair. Here a two-way repeated-measures ANOVA showed a significant main effect between the 'static' and 'interactive' conditions, $F(1, 22) = 14.65, p < 0.01$ but after Holm-Bonferroni correction no significant main effect between the two experiments, $F(1, 22) = 4.80, p = 0.11$. The interaction between the factors

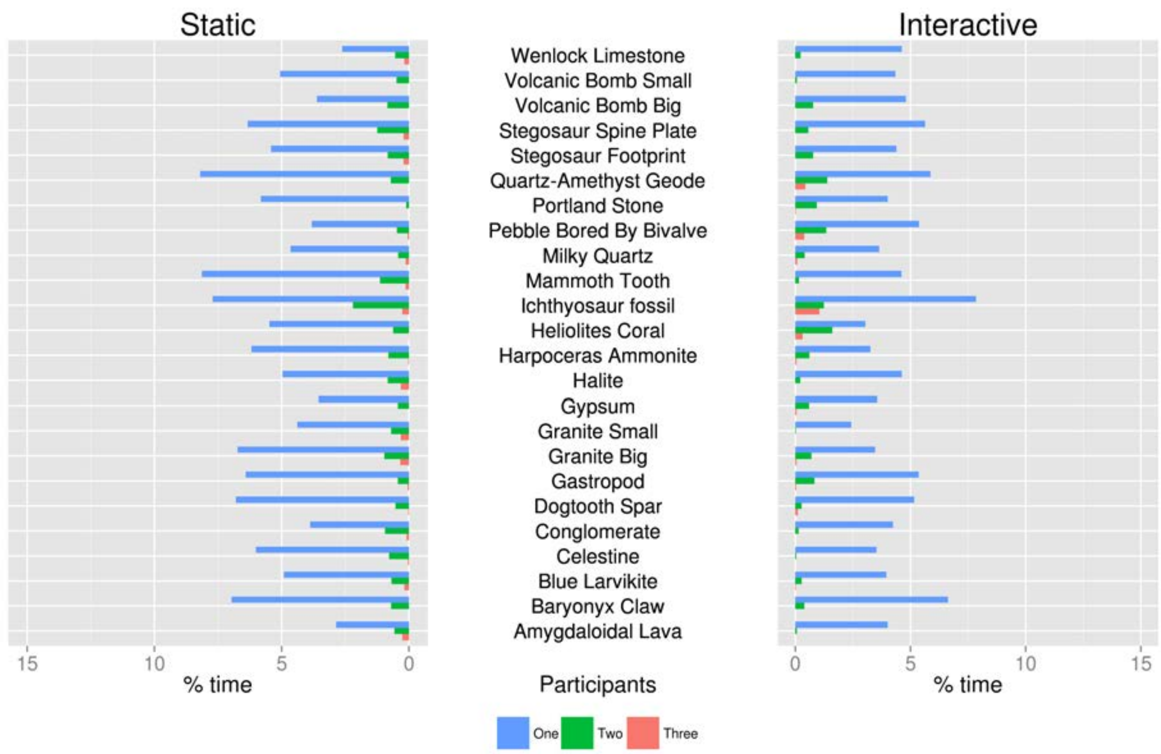



Figure 6.9: Average time participants spent at the artefacts alone, in pairs, and as trio, with values for the ‘static’ condition on the left, and for the ‘interactive’ condition on the right.

interaction and group composition was not significant, $F(1, 22) = 0.17, p = 1.00$. For the time participants spent interacting with the artefacts alone, a two-way repeated-measures ANOVA showed a significant main effect between the ‘static’ and ‘interactive’ conditions, $F(1, 22) = 22.65, p = 0.001$ but no significant main effect between the two experiments, $F(1, 22) = 2.23, p = 0.80$. Also, the interaction between the factors interaction and group composition was not significant, $F(1, 22) = 2.40, p = 0.80$.

## 6.5 Discussion

The study described in this chapter strengthens findings of the experiment described in chapter 5 but also provides new insights in group behaviour during a visit to a temporary museum exhibition.

First of all this study shows that during the ‘interactive’ condition participants spent more time at the tabletop but also less time at the actual museum artefacts compared to the ‘static’ condition. These findings are in line with the results from the study described in chapter 5 and once again illustrate that museums should carefully consider the setup of their interactive tabletops and what they want their visitors to take away from their visit. The study also shows that although group composition had no effect on the time spent at the tabletop, groups of family or friends spent on average more time interacting with museum artefacts than groups of individuals. This is further supported by the time participants spent together as a trio interacting with the museum artefacts which was significantly longer for groups of family or friends compared to groups of individuals.

Additionally, the results show that group composition has an effect on the average distance between participants. The previous experiment already showed that groups of individuals spent more time closer together during the ‘interactive’ condition compared to the ‘static’ condition. However, allowing participants to further explore museum artefacts on the interactive tabletop had no such effect on groups of family or friends. This would suggest that although an interactive tabletop can bring people closer together, this is specifically of interest for the social experience of individuals as groups of family or friends already spent more time close together.

When looking at Hall’s four social zones, it shows that participants spent more time close together during the ‘interactive’ condition compared to the ‘static’ condition. Although it was expected that groups of family or friends would spend more time in the intimate and personal zones compared to groups of individuals, no significant differences were found. A closer look at the time spent in the personal zone shows that groups of individuals spent more time in the personal zone during the ‘interactive’ condition (21%) than during the ‘static’ condition (17%). However, groups of family or friends spent more time in the personal zone during the ‘static’ condition (24%) than during the ‘interactive’ condition (20%). This would suggest that during the ‘interactive’ condition groups of individuals were drawn towards the personal zone whereas groups of family or friends were pulled out of it. One explanation for this could be the size of the interactive tabletop. Results have already shown that participants spent more time at the interactive tabletop during the 'interactive' condition. However, as the size of the interactive tabletop is 172 centimetres by 108 centimetres it is likely that time spent around the interactive tabletop would fall within the social zone (120 - 360 cm), and not within the personal zone (45 - 120 cm). This is further supported by the difference in the time spent in the social zone which was significantly longer during the 'interactive' compared to the 'static' condition.

Although a smaller interactive tabletop might result in participants spending more time in the personal zone, it might also be less inviting for individuals when others are interacting with it. The higher levels of attentional engagement during the interactive condition in the previous experiment go hand in hand with a significant increase in time spent at the interactive tabletop. Although the difference in levels of attentional engagement were then not significant, this experiment provides some new insights into these findings. The results show that groups of family or friends paid significantly more attention to the actions of their group members than groups of individuals during the 'static' condition. However, between the 'interactive' and 'static' conditions there was only a significant difference for groups of individuals. This would suggest that allowing participants to further explore museum artefacts on the interactive tabletop had no effect on groups of family or friends in terms of attentional engagement. However, it also indicates that bringing groups of individuals around an interactive tabletop gives them the opportunity, or forces them, to pay more attention to each others' actions. As this difference only occurred for groups of individuals, it would be more likely that it would 'force' participants, and not 'provide the opportunity', to pay more attention to actions of others. This would then stem from the assumption that social boundaries would already have been crossed within groups of family or friends, which was why individuals were invited to take part in the study described in chapter 5.

Although no differences were expected for the cognitive absorption factors, results showed that groups of individuals scored significantly higher than groups of family or friends on levels of control. Although the previous two experiments have shown that participants were able to adapt to novel interaction modalities, there is still a steep learning curve for using these new technologies. However, even though the 'interactive' condition offered more novel interaction modalities, levels of control were higher compared to the 'static' condition. An explanation might be that during the 'static' condition participants tried to interact with the tabletop but, as it was just a static image, failed to do so. As participants expected to be able to interact with the tabletop, but could not figure out how to use it, this could have confused them, resulting in lower levels of control for the 'static' condition. During the 'interactive' condition however, participants were able to interact with the tabletop and even though it offered more novel interaction modalities participants figured out how to use it quite quickly. Moreover, groups of individuals might have had to figure out the workings of the interaction modalities by themselves (e.g. by paying attention to the actions of others), whereas groups of family or friends might have relied on a group member to figure out how the interactive tabletop worked and then have it explained to them.

Finally, higher levels of co-presence were also expected during this study compared to the study described in chapter 5. However, no differences were found. Possibly the construction of the questionnaire might have influenced the results as key terms were adjusted to fit the experiment and "my partner" was adjusted to "my group". Results then suggest that groups of individuals did not feel as belonging to a group even though they visited the exhibition together.

Overall the results from this study are in line with the previous experiment indicating that allowing participants to further explore museum artefacts on the interactive tabletop can engage participants and extend their interaction time when being alone, in pairs, or together as a group. In addition, this study provides some new insights in group behaviour during a visit to a temporary museum exhibition for groups of family or friends and groups of individuals. Levels of attentional engagement were significantly higher during the 'interactive' condition for groups of individuals compared to groups of family or friends and participants moved from the public zone to the social zone when they were able to interact with an interactive tabletop. Given the intended purpose of the overall project, it would be of interest to investigate changes in cognitive absorption with a more interactive setup (e.g. an interactive tabletop which offers a more complex interaction) and study the combinations of mobile and stationary technologies in an actual museum environment.

# Chapter 7
# Evaluating In-Lab and In-The-Wild Studies

So far the studies described in chapters 4 to 6 examined the effects of combining mobile and stationary technologies in a controlled setting. For the intended purpose of this thesis this final study builds on the previous studies and investigates the effects of combining these technologies in an actual museum environment.

## 7.1 Introduction

The methodology of this thesis already highlights the issue that when running experiments in order to test ubiquitous computing technologies there is a trade-off between a controlled environment and their intended setting (see chapter 3). So far the Prototyping Hall at the Digital Humanities Hub at the University of Birmingham has provided a unique environment where real world situations were simulated for user testing. These experiments have provided unique insights in user interaction as well as group behaviour. Although some findings, such as the preferred smartphone interaction from chapter 4 or the difference in levels of attentional engagement from chapter 6, might also have been found during in-the-wild studies. Other findings, such as the shortened interaction time with actual museum artefacts from chapter 5 would have been difficult for in-the-wild experiments. On the other hand, during the previous studies participants do follow a predetermined protocol and the question "how people appropriate technologies in their intended setting" [69] still remains.

As the intended purpose of this thesis is to feed into the development of future applications for interactive exhibits and to contribute to the understanding of how combinations of new technology can influence visitor behaviour, this would not be complete without covering both the controlled environment and the intended setting for these technologies. This includes doing both in-lab and in-the-wild studies. In addition, this will also give a holistic overview of applying new technologies within a museum, from in-lab experiments to in-the-wild applications and illustrate the strengths and weaknesses of both setups. The purpose of the study described in this chapter is therefore to examine the influence of mobile and stationary technologies on museum visitors in an in-the-wild setting in order to compare and complement the findings from the previous in-lab studies.

## 7.2 Methodology

The previous studies have provided valuable insights in the perceived experiences of museum visitors in terms of perceived usability, social presence and cognitive absorption. However, how these findings transfer to an actual museum remains something to be investigated and forms the basis of the study described in this chapter which addresses the following research question:

- What are the effects of combining mobile and stationary technologies in a museum environment on visitor experiences?

In order to find an answer to this research question the experimental setup of chapters 5 and 6 is applied in an actual museum, the Lapworth Museum of Geology. To test a number of hypotheses an experiment is designed in which visitors can interact with an interactive tabletop, mobile technologies, or a combination of the two. As visitors might be reluctant to complete long questionnaires, a subset of the questionnaires from the previous studies is used. For this experiment three main factors are important. Usability, do users experience this similar in-the-wild compared to in-lab studies. Attentional engagement, this factor was influenced by an interactive tabletop as well as by group composition. Both will occur in the museum which is why this factor will be tested. Finally, cognitive absorption. Previous studies already suggest that by increasing the interactivity on the interactive tabletop this will result in higher levels of cognitive absorption. As a new application will be developed for this experiment the increase of interactivity is taken into account and should therefore be tested. Although the setup of the experiment is different, the application of the technologies remains the same as in the studies described in chapters 5 and 6. This also allows for a close examination of differences between in-lab and in-the-wild experiments. This resulted in a second research question which was also examined during this study.

- How do evaluations of technologies differ from in-lab to in-the-wild studies?

Using the SUS questionnaires from the experiment in chapter 4 participants' perception of usability can be measured, evaluated, analysed and compared. For the attentional engagement and cognitive absorption a subset of the questionnaires from the experiment in chapter 5 is used.

## 7.3 Experiment

In order to answer the final two research questions, "What are the effects of combining mobile and stationary technologies in a museum environment on visitor experiences?" and "How do evaluations of technologies differ from in-lab to in-the-wild studies?" an experiment was designed which will be further described in this section. For the overall purpose of this thesis the final study took place at an actual museum, the Lapworth Museum of Geology. The study lasted for two weeks during which visitors to the museum were invited to participate in the study. The first week of the study coincided with the

British Science Festival 2014 which took place in Birmingham, United Kingdom from 6 to 11 September. However, as this week resulted in only a few participants the study was extended with one week.

### 7.3.1 Participants

During the two weeks of the exhibition 219 people visited the Lapworth Museum of Geology. Out of these 219 visitors 23 agreed to take part in the study. The participants (13 female and 10 male) were aged between 4 and 68 years ($\mu = 37.17, \sigma = 16.77$) and indicated they visited the Lapworth Museum of Geology alone (12 out of 23), as a pair (9 out of 23) or as a group (one group of 4 and one group of 6). Out of the 23 participants 17 owned a smartphone and about two third (16 out of 23) had visited a museum within the last 3 months. When asked with whom they normally visit a museum they indicated visiting museums with friends (12 out of 23), family (17 out of 23), partner (9 out of 23) and alone (7 out of 23). Before entering the museum all visitors were made aware that by visiting the exhibition they gave their consent for the use of any video footage and data collected for research purposes. In case visitors wished to withdraw from the study they could speak with the researcher, or contact a member of staff, to have any interactions they have had with display cases, technologies, and other visitors be removed before data analysis.

### 7.3.2 Setup

The Lapworth Museum of Geology itself was founded in 1880 and under the direction of Charles Lapworth its collection grew rapidly. The current collection nearly reaches 250.000 artefacts covering many aspects of geological sciences (e.g. palaeontology, mineralogy, petrology). Located at the University of Birmingham the museum offers an important resource for anyone who has the desire to study or learn about geology. Within the museum most of the artefacts are placed in display cases sorted by common themes (see figure 7.1).

For the experiment the exhibitions on ‘stratigraphic palaeontology’ and on the ‘main

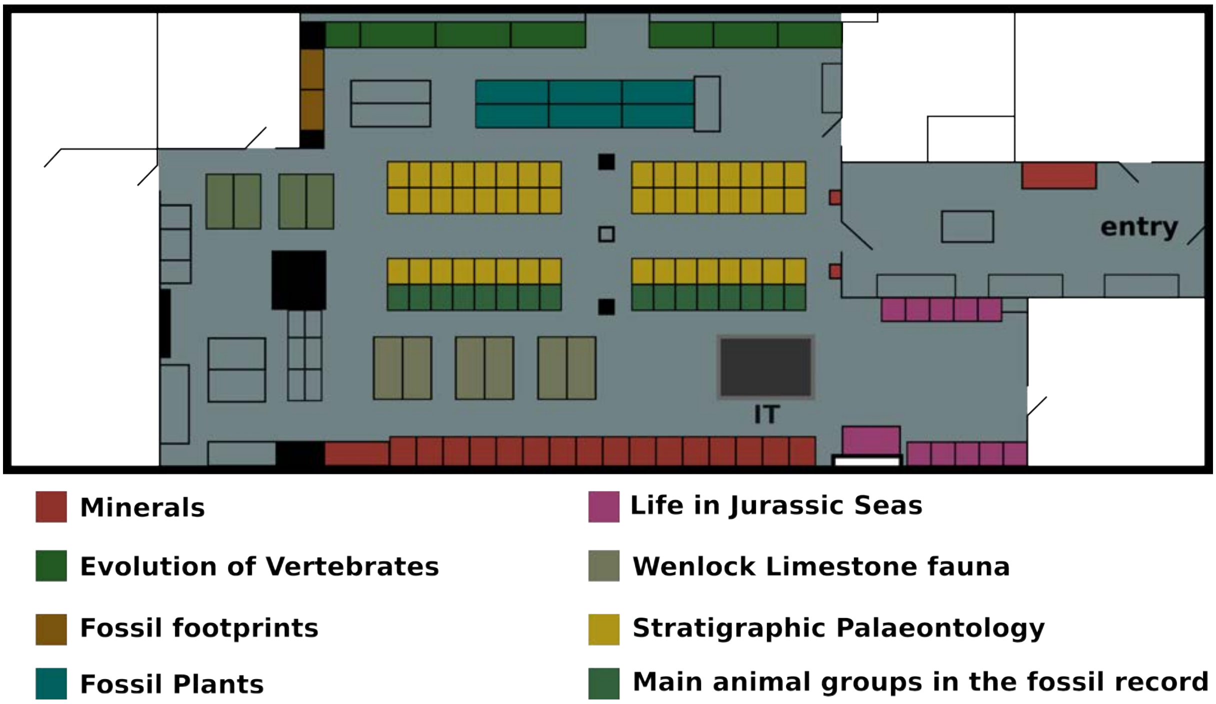



Figure 7.1: Layout of the Lapworth Museum of Geology showing the eight main display themes and the interactive tabletop (IT).

animal groups in the fossil record' were used. Both exhibitions are located immediately at the entrance to the museum and combined contain nearly half of the museum's displayed collection. The 'stratigraphic palaeontology' exhibition is arranged over 48 display cases and covers the geologic time scale. Each of its display cases shows some artefacts from a specific geological period. The exhibition on the 'main animal groups in the fossil record' consists of 16 display cases which show fossils from sponges and choral to echinoderms (e.g. starfish) and chordates (e.g. reptiles). Additionally, an interactive tabletop was placed next to the two exhibitions (see figure 7.1).

In contrast to the experiments in chapters 5 and 6 where participants were invited to take part in the study, for this experiment visitors to the Lapworth Museum of Geology were asked to take part in the study. Visitors who agreed to take part in the study (see table 7.1) were instructed on the use of the smartphone and NFC pads after which they were given a smartphone. Throughout the museum signposts provided additional information about the study for all visitors (see appendix K). As visitors to the museum could choose not to partake in the experiment this had to be taken into account when designing and

| Group | Age | Gender | Mother Tongue | Acquaintanceship |
|---|---|---|---|---|
| **1** | 18.00 ( 0.00) | 2M | 2 English | Friends |
| **2** | 46.50 (28.99) | 1F / 1M | 2 English | Friends |
| **3** | 52.50 (21.92) | 1F / 1M | 2 German | Friends |
| **4** | 28.00 ( 0.00) | 1F | 1 English | Alone |
| **5** | 37.00 (14.80) | 1F / 2M | 3 English | Family of six |
| **6** | 32.50 ( 0.71) | 1F / 1M | 1 Chinese<br>1 English | Partners |
| **7** | 56.00 ( 0.00) | 1F | 1 English | Alone |
| **8** | 41.00 ( 0.00) | 1F | 1 English | Alone |
| **9** | 41.00 ( 0.00) | 1F | 1 English | Alone |
| **10** | 4.00 ( 0.00) | 1F | 1 English | Mother and daughter |
| **11** | 52.50 ( 0.71) | 1F / 1M | 1 English<br>1 Italian | Partners |
| **12** | 46.50 ( 6.36) | 1F / 1M | 2 English | Partners |
| **13** | 41.00 ( 0.00) | 1F | 1 Punjabi | Family of four |
| **14** | 18.00 ( 0.00) | 1F / 1M | 2 English | Friends |

Table 7.1: Participants and composition of their groups, showing age (represented as $\mu(\sigma)$), gender (represented as Female / Male), mother tongue and acquaintanceship.

developing the interactive tabletop application. The study described in chapter 6 suggests that by showing just a static image visitors could get confused. Therefore, some basic level of interaction with the interactive tabletop has to be offered to all visitors, whether they participate in the study or not. The application running on the interactive tabletop was designed to represent the layout of the two exhibitions and showed a floor plan with the 64 display cases. When visitors tapped one of the display case on the interactive tabletop, they would get to see a description of the display case (see figure 7.2). This is also the first condition of this experiment, the 'tabletop' condition during which participants can only interact with the interactive tabletop.

For the second condition the display cases of the two exhibitions were fitted with NFC tags to incorporate them into an interactive setup. During this condition participants were given an NFC enabled smartphone before entering the museum environment, hence the condition was labelled 'mobile'. The smartphone allowed participants to interact with the display cases. Once participants scanned an NFC tag with the smartphone a pre-installed

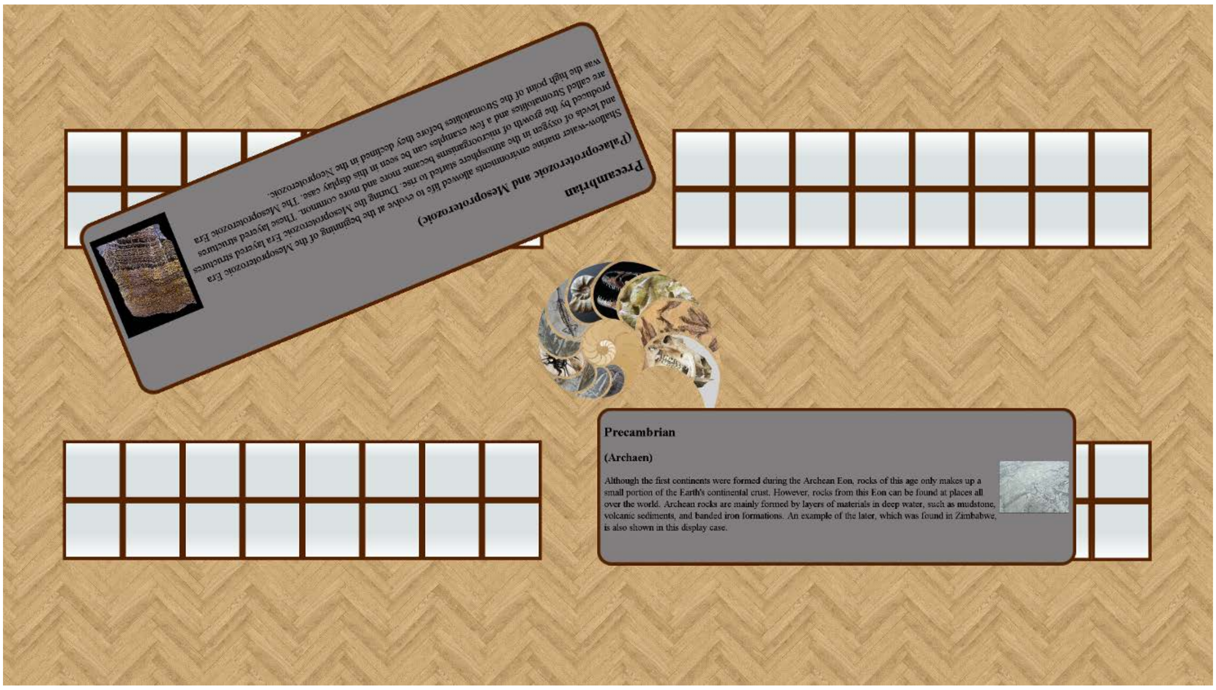
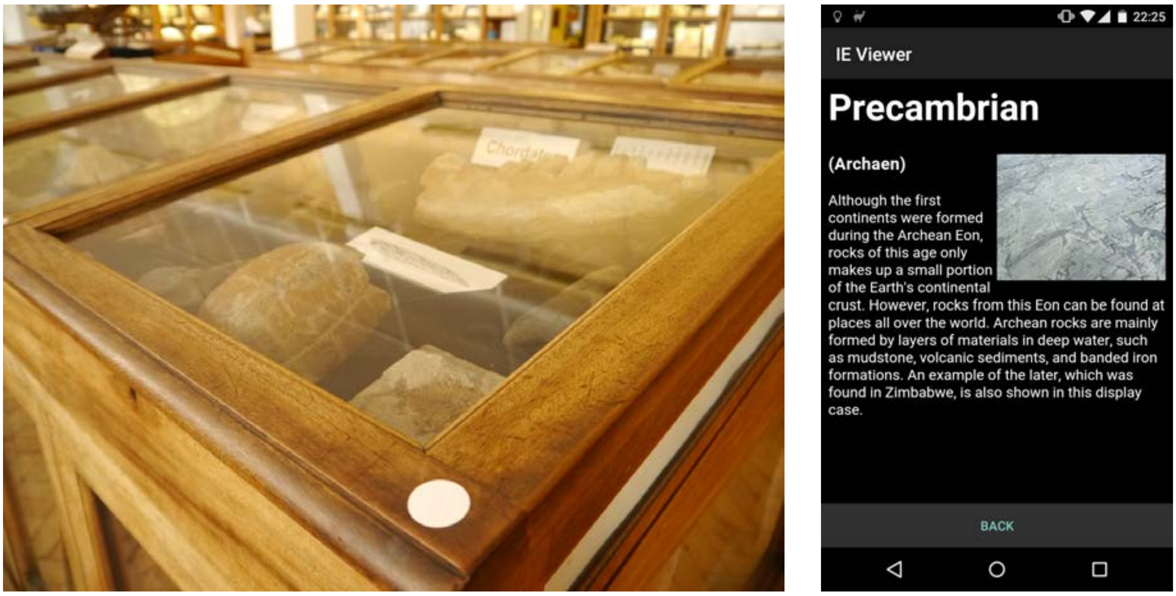



Figure 7.2: Tabletop application showing the two exhibitions and information about two display cases.

Android application was launched and showed them relevant information about the display case. As these tags did not represent a single artefact but rather a whole display case, participants were presented with a description of the display case as in the 'tabletop' condition (see figure 7.3).

As with the studies described in chapters 5 and 6, participants were also able to collect a virtual representation of the display cases on their smartphone. Additionally, the Android application allowed participants to view a list of collected display cases and view its information at any time. Finally, in order to allow participants further interaction with both the display cases and the interactive tabletop, the third condition of this experiment combined these technologies and allowed participants to connect their smartphone to the interactive tabletop. During this condition the interactive tabletop was fitted with four NFC tags, one on each side. When participants connected their smartphone to the interactive tabletop, an avatar was shown on the tabletop to illustrate the smartphone was connected. Additionally, information about visitor interaction with the display cases was retrieved and the application on the tabletop would show participants which




(a) (b)

Figure 7.3: Display case with an NFC pad for user interaction (a), and smartphone interaction with a display case from the stratigraphic palaeontology exhibition (b)

(a) (b)

Figure 7.4: Interaction with interactive tabletop showing visited display cases (a), and additional information (b)

display cases they had visited (see figure 7.4a).

As with the previous experiments participants could also select and send collected display cases from their smartphone to the interactive tabletop. Once a display case was received by the interactive tabletop, additional information was retrieved and shown on screen. As the interactive tabletop already showed display case information for any visitor, participants would get to see a high resolution image related to the selected display case (see figure 7.4b). This final condition was labelled 'combined'.

### 7.3.3 Data Acquisition

After their visit, and before they left the museum, participants were asked to complete a questionnaire on paper (see appendix L). In order to keep the questionnaire short 30 statements were selected from questionnaires used during the previous studies.

#### Social Presence

In the experiment described in chapter 6 combining mobile with stationary technologies had, in terms of attentional engagement, no effect on groups of family or friends but did have an effect on groups of individuals. As an actual museum environment is often a combination of both, six statements related to the attentional engagement factor of Biocca's 'Networked Minds Social Presence Inventory' were selected to measure participants attentional engagement [9]. It is expected that visitors to the Lapworth Museum of Geology will be a combination of groups of family or friends, but also individuals. For the levels of attentional engagement this means that, in line with the results from the experiment described in chapter 6, participants who are part of a group will have lower levels during the 'combined' condition compared to the 'tabletop' or 'mobile' conditions. In addition, it is expected that participants who visit the museum alone will have higher levels during the 'tabletop' condition compared to the 'mobile' or 'combined' conditions.

#### Cognitive Absorption

The experiment described in chapter 6 also suggests that a more interactive application on the tabletop could result in higher levels of cognitive absorption. In order to allow all visitors to use the interactive tabletop some basic level of interaction with the interactive tabletop is offered to all visitors during this experiment and a more extensive interaction for participants. To measure their levels of cognitive absorption 14 statements of Agarwall's questionnaire on cognitive absorption were selected. As participants during the ‘combined’ condition will have a more complex and extensive interaction it is expected that they will have higher levels of cognitive absorption compared to participants in the ‘tabletop’ or ‘mobile’ conditions.

#### Perception of Usability

Additionally, in order to validate the results from the experiment described in chapter 4 with visitors to an actual museum ten statements of the SUS were selected to measure participants’ perception of usability of the combination of technologies. In line with the results from the experiment described in chapter 4 it is expected that the usability scores will be high for all conditions. As groups of family or friends reported lower levels of control in the study described in chapter 6, it was also expected that the usability score for groups would be lower than for individuals.

#### User Tracking

Finally, as with the experiments from chapters 5 and 6, a video camera was mounted on a wall providing a bird’s-eye view of the interactive tabletop and the two exhibitions (see figure 7.5). As it was not possible to track users movements through the museum environment, the video camera was first and foremost used to record visitors’ interactions during their visit. Furthermore, all smartphone interactions were recorded during the ‘mobile’ and ‘combined’ conditions and tabletop interaction was recorded during all three conditions. For the interactions with the tabletop it is expected that during the ‘combined’ condition these will be longer compared to the ‘mobile’ and ‘tabletop’ conditions.

Figure 7.5: A bird's-eye view of the two exhibitions and the interactive tabletop.

### 7.3.4 Analysis

After the two weeks of the experiment questionnaires were digitised and video recordings were analysed. In addition, the provided smartphones recorded user interaction which allowed analysis of interactions with display cases and the interactive tabletop. For the video analysis the following four events were annotated:

1. New visitor enters the museum.
2. Visitor uses the interactive tabletop.
3. Visitor uses mobile phone to interact with display case.
4. Visitor uses mobile phone to interact with interactive tabletop.

For the questionnaires ratings were obtained for the factors of the SUS, the attentional engagement factor of the 'Networked Minds Social Presence Inventory' and for the factors of cognitive absorption. All ratings were normalised and extreme values were adjusted to 3 standard deviations. Ratings were then tested for normality and since each participant only took part in one condition, ratings were compared using either a Kruskal-Wallis Test or a one-way ANOVA to determine if there was a significant difference between the three conditions. The same was done for the results of the video annotations. In case of multiple comparisons the Holm-Bonferroni correction was used with a combined significance of $p \leq 0.05$ for each of the different measurements.

## 7.4 Results

After the second week of the experiment at the Lapworth Museum of Geology questionnaires were digitised and video recordings were annotated. The following section describes the analysis of the results of the questionnaires and the analysis of the recordings.

### 7.4.1 Questionnaires

#### Social Presence

First, the results of attentional engagement factor of the 'Networked Minds Social Presence Inventory' was analysed (see figure 7.6). For this factor no significant difference was found between the 'tabletop' ($\mu = 72.38, \sigma = 3.61$), the 'mobile' ($\mu = 53.81, \sigma = 5.98$) and the 'combined' ($\mu = 60.71, \sigma = 20.08$) conditions, $F(2, 15) = 2.21, p = 0.15$. This would suggest participants paid no more attention to, and were not more aware of, the action of their group members in any of the three conditions.

However, in line with the results of the experiment described in chapter 6 it was expected that the difference in group composition would have an impact on participants' perception of attentional engagement. For this a 2(group: 'unknown' vs. 'familiar') x 3(interaction: 'tabletop' vs. 'mobile' vs. 'combined') independent ANOVA was conducted to study the perceived levels of attentional engagement between conditions and group compositions. It was expected that participants who were part of a group would have lower levels during the 'combined' condition compared to the 'tabletop' or 'mobile' conditions and that participants who visited the museum alone would have higher levels during the 'tabletop'

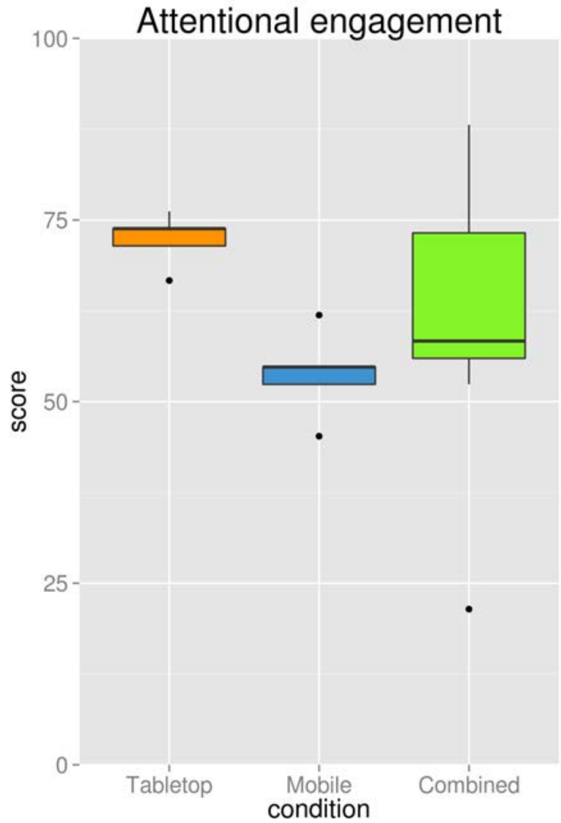



Figure 7.6: Normalised ratings for participants' perception of attentional engagement.

condition compared to the 'mobile' or 'combined' conditions. However, analysis showed no significant main effect for the interaction factor, $F(2, 13) = 1.99, p = 0.18$ and no significant main effect for the group factor, $F(1, 13) = 0.03, p = 0.88$. Also, the interaction between the factors interaction and group was not significant, $F(1, 13) = 0.50, p = 0.50$.

### Cognitive Absorption

Secondly, the results of the Cognitive Absorption questionnaire was analysed (see table 7.2). It was expected that by offering more complex interaction on the interactive tabletop participants would have higher levels of cognitive absorption in the 'combined' condition compared to the 'tabletop' and 'mobile' conditions. However, looking at the results participants' ratings for the cognitive absorption factor was lowest for the 'combined' condition. A one-way ANOVA determined there was no statistically significant difference

| | Tabletop | Mobile | Combined |
|---|---|---|---|
| **Cognitive Absorption** | 83.67 ( 6.65) | 82.65 ( 6.34) | 79.59 (14.63) |
| **Temporal Dissociation** | 82.86 ( 9.35) | 82.86 ( 8.86) | 85.71 (17.44) |
| **Focused Immersion** | 77.14 ( 6.58) | 81.43 ( 8.50) | 74.29 (18.40) |
| **Heightened Enjoyment** | 96.43 ( 7.41) | 85.71 ( 8.75) | 85.71 (11.84) |

Table 7.2: Normalised ratings for cognitive absorption and its five factors. Values are represented as $\tilde{x}(\sigma)$.

for the cognitive absorption factor between the 'tabletop' ($\mu = 84.69, \sigma = 6.65$), the 'mobile' ($\mu = 83.67, \sigma = 6.34$) and the 'combined' ($\mu = 78.43, \sigma = 14.63$) conditions, $F(2, 17) = 0.72, p = 1.00$ (after Holm-Bonferroni correction for four comparisons).

Additionally, no significant differences were found between the two conditions for the factors temporal dissociation and focused immersion, $F(2, 19) = 0.11, p = 1.00$, and $F(2, 17) = 1.10, p = 1.00$ respectively. Also, for the heightened enjoyment factor no significant difference was found between the 'tabletop' ($\mu = 94.29, \sigma = 7.41$), the 'mobile' ($\mu = 88.10, \sigma = 8.75$) and the 'combined' ($\mu = 85.27, \sigma = 11.84$) conditions, $F(2, 19) = 1.32, p = 1.00$.

### System Usability Scale

Finally, the results of SUS questionnaire was analysed and used to determine participants' perception of usability and learnability of the different conditions. In line with the results of the experiment described in chapter 4, the conditions with mobile interaction (i.e. 'mobile' and 'combined') scored higher compared to the 'tabletop' condition (see figure 7.7). However, a Kruskal-Wallis, with Holm-Bonferroni correction for three comparisons, showed no statistically significant difference in perceived ease-of-use between the three different conditions ($\chi^2(2) = 2.90, p = 0.51$) with a mean rank of 75.71 for the 'tabletop' condition, 88.57 for the 'mobile' condition and 85.36 for the 'combined' condition.

When investigating the SUS questionnaire further, looking at the usability and learnability dimensions (see figure 7.8), this revealed a similar difference for the usability dimension, whereas for the learnability dimension their seems to be a small difference between all

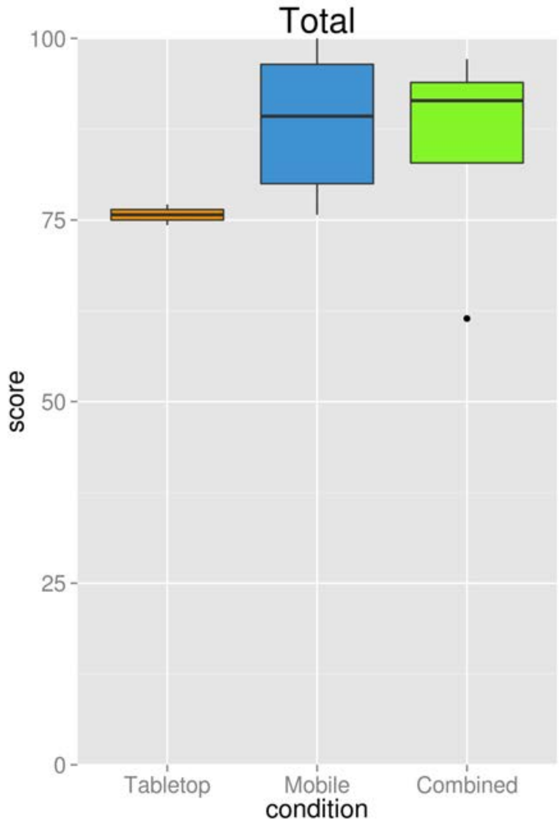
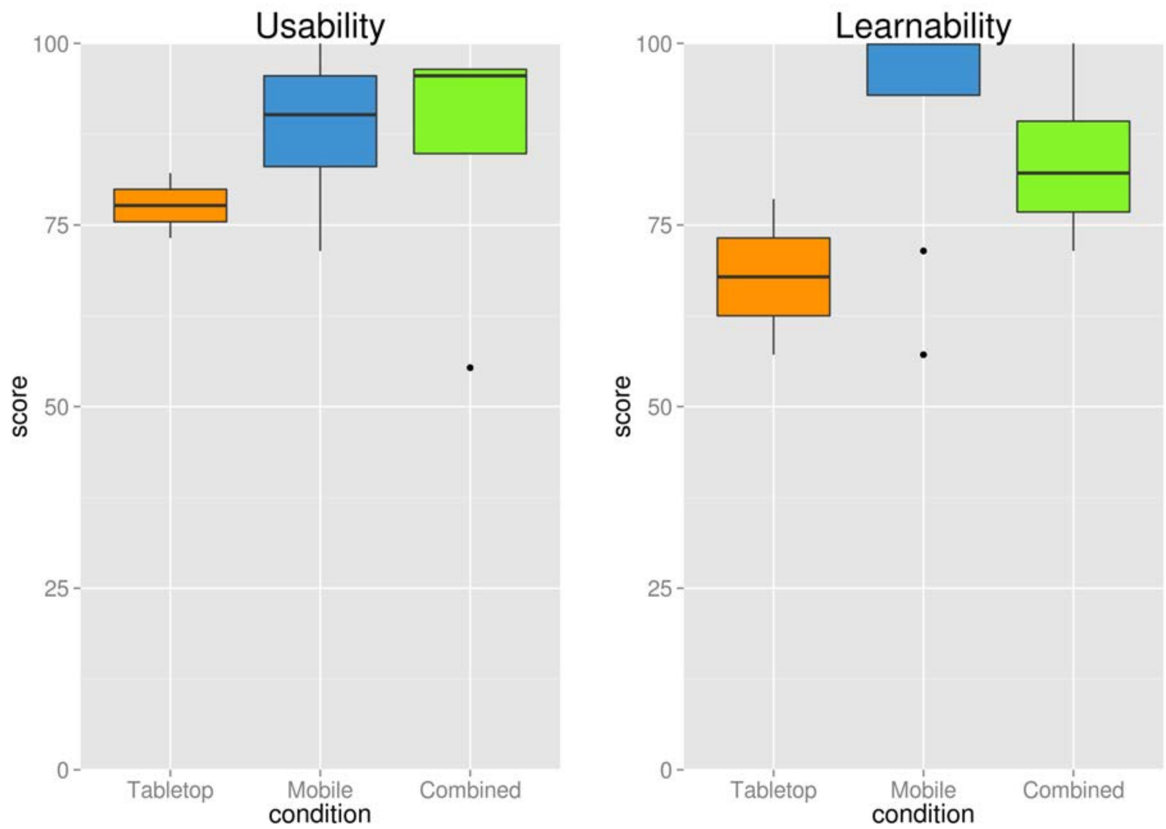



Figure 7.7: Normalised ratings for overall perceived ease-of-use

conditions. However, for the usability dimension the difference between the three different conditions appeared to be nonsignificant ($\chi^2(2) = 1.67, p = 0.51$) with a mean rank of 77.68 for the 'tabletop' condition, 88.17 for the 'mobile' condition and 85.71 for the 'combined' condition. For the learnability dimension the difference between the three conditions, with a mean rank of 67.86 for the 'tabletop' condition, 91.27 for the 'mobile' condition and 83.93 for the 'combined' condition, was also nonsignificant ($\chi^2(2) = 3.54, p = 0.51$).




(a) (b)

Figure 7.8: Normalised ratings for (a) usability , and (b) learnability dimensions of the SUS questionnaire

### 7.4.2 Video Analysis

#### Tabletop interactions

During the experiment 28 hours and 41 minutes of video was recorded. The recordings were annotated and data was extracted for analysis. A total of 219 people visited the Lapworth Museum of Geology during the two weeks of the experiment. The number of people visiting the museum varied per day and although on average 24.3 people visited the museum per day, some days were very quiet with only three visitors whereas other days were more crowded with 102 visitors. During their visit both visitors as participants interacted with the interactive tabletop. Although the number interactions did not differ greatly between the three conditions (19 interactions during the 'tabletop' condition, 33 interactions during the 'mobile' condition and 30 interactions during the 'combined' condition), there seems to

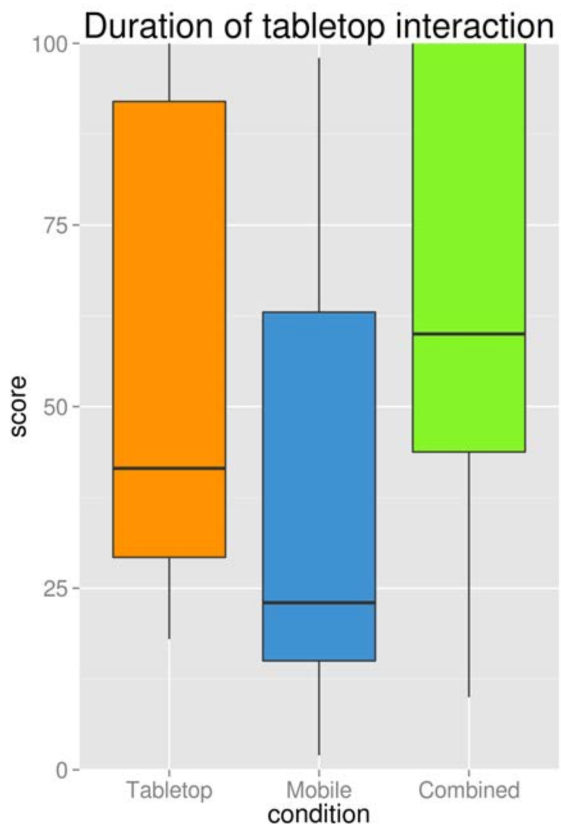



Figure 7.9: Duration of interactions with the interactive tabletop

be a difference in interaction duration (see figure 7.9). However, a Kruskal-Wallis showed no statistically significant difference in interaction duration between the three different conditions ($\chi^2(2) = 5.65, p = 0.06$) with a mean rank of 56.83 for the 'tabletop' condition, 48.05 for the 'mobile' condition and 114.40 for the 'combined' condition.

### 7.4.3 Recorded interactions

#### Smartphone interactions

During the 'tabletop' condition visitors and participants were only able to interact with the interactive tabletop. Smartphone interaction was therefore only available during the 'mobile' and 'combined' conditions. When looking at the smartphone interaction with the display cases, the smartphones were used 287 times to scan one of the NFC tags next to

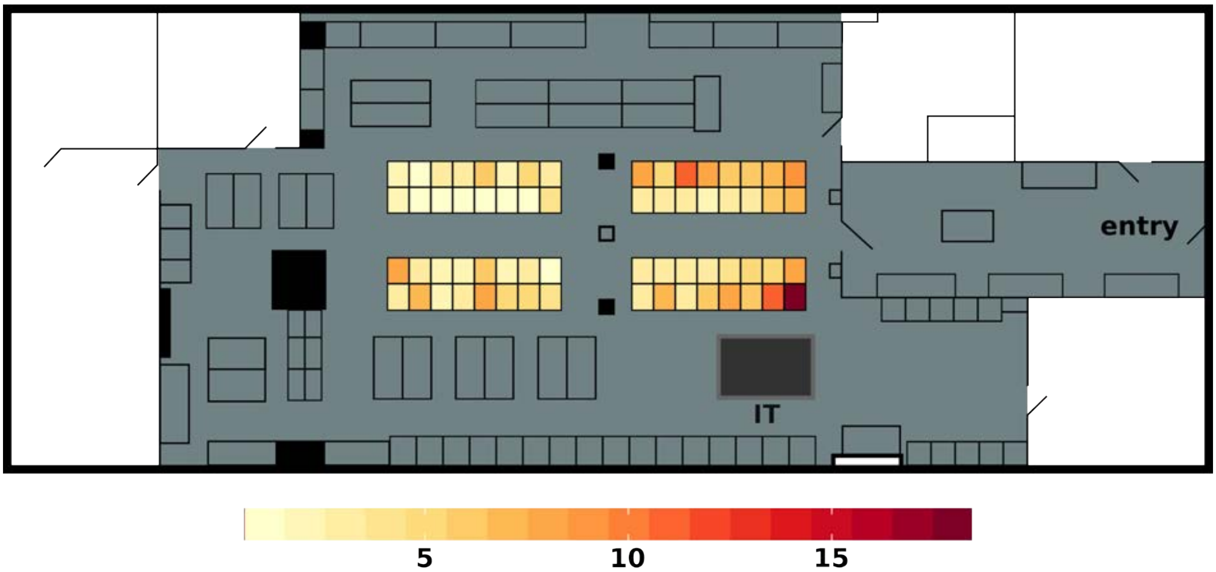



Figure 7.10: Heat-map of participant interaction with the display cases. Darker colours indicate more interaction.

the display cases. As with the experiments from chapters 5 and 6 some display cases were more popular than others (see figure 7.10). Figure 7.10 shows a heat-map of the display cases where darker colours indicate more interaction. It shows that the display cases near the entrance and the ones next to the interactive tabletop have been interacted with more compared to others.

In addition, the recorded interactions allows for determining smartphone interaction time with the display cases (see figure 7.11). The average duration participants interacted with a display case using the smartphone in the 'mobile' and 'combined' conditions was 28.72 seconds. This includes scanning the NFC tag and reading the information on screen. It was expected that by increasing the interactivity on the interactive tabletop for participants during the 'combined' condition, the average interaction time would decrease as participants would move on to the interactive tabletop for further exploration. Although the median interaction time for the 'combined' condition is indeed lower ($\tilde{x} = 9$) compared to the median interaction time for the 'mobile' condition ($\tilde{x} = 27$), a Mann-Whitney U test indicated that this difference was not significant, $Z = -1.75, p = 0.08$.

Next to the interaction with the display cases, the final condition also allowed participants

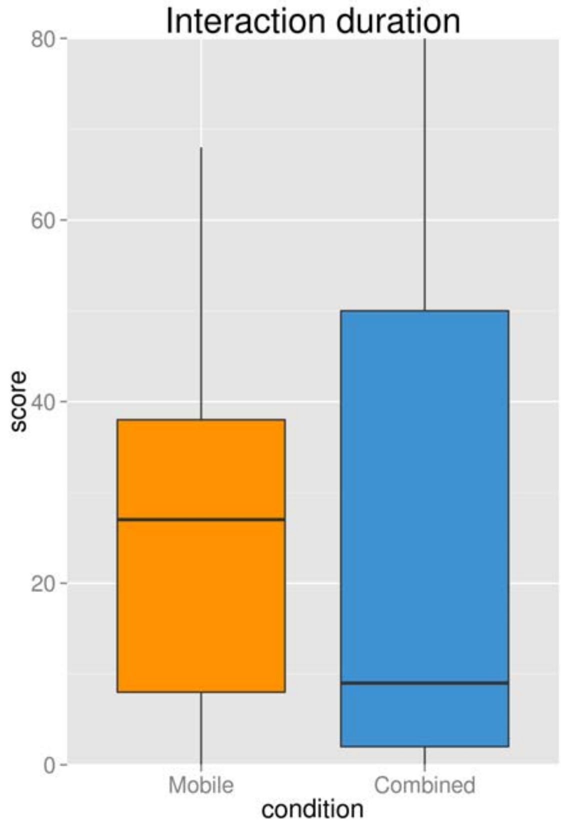



Figure 7.11: Duration of display case interaction with smartphone

to collect display cases on the smartphones and use these at the in the interactive tabletop for further exploration and interaction. During the 'combined' condition participants collected 10 display cases and used the smartphone for connecting with the interactive tabletop 9 times. During these interactions of combined technologies a total of 19 display cases were sent to the interactive tabletop. On average these interactions lasted 155 seconds ($\sigma = 336$ seconds).

## 7.5 Discussion

The purpose of the study described in this chapter was to compare and complement the findings from the previous in-lab studies with an in-the-wild setting. The study examined the influence of mobile and stationary technologies on museum visitors and recorded their interactions through video recordings, device interactions and in addition a short questionnaire. In terms of complementing the findings from the previous in-lab experiments, this study provides some new insights into the use of technologies and user testing in museums as a whole. However, in terms of comparing the findings from the previous in-lab studies, this study shows some unexpected differences.

First of all it was difficult to find visitors to participate. Out of the 219 visitors only 23 agreed to participate in the experiment. Although this 10% is smaller to other studies where museum visitors were invited to participate in an experiment (e.g. Grinter *et al.* [33] who had a 40% success rate), they all require an almost 100% attendance of a researcher. Especially during quiet days valuable time is lost compared to the in-lab experiments where sessions were scheduled and participants were invited. Furthermore, once visitors agreed to participate, following a set protocol proved hard. Although visitors were made aware of the interactive tabletop, this did not mean they would also use it. Some of them even indicated they had not seen the interactive tabletop during their visit. Similar situations occurred during the 'mobile' and 'combined' conditions where some participants preferred not to use the smartphone to interact with the display cases (in these cases they were placed in the 'tabletop' condition). Others indicated they had not used the smartphone during their visit and a couple who preferred to share the smartphone. There were also cases where a group of visitors would enter the museum but only one or two of them agreed to partake in the study. Video recordings also show this resulted in participants handing over the smartphone to one of their friends or family members.

Finally, when leaving the museum and when asked to complete a short questionnaire other issues occurred. Some participants were short on time whereas others completed

(a)

(b)

Figure 7.12: Visitors exploring the display cases together, either sharing a smartphone (a), or having one each (b).

the questionnaire with their kids, forgot (or ignored) some questions, or even provided incorrect data (for example reporting being alone when they entered and left the museum as part of a group). As a result some questionnaires were incomplete or incorrect which made analysing the results challenging. This might also explain why no differences were found for the attentional engagement factor which were expected based on the results of the experiments in chapters 5 and 6. For the SUS questionnaire the learnability scale indicated participants believed they needed time, and possibly help, to learn how to use the smartphone or interactive tabletop. However, in line with the previous experiments participants quickly learned how to use either the smartphone to scan NFC tags, or how to use the interactive tabletop. As the total usability was high for all conditions it would suggest that the learning curve is short but steep.

Despite these issues, the findings provide valuable insights in testing (combination of) technologies in an in-the-wild setting. Whether sharing one smartphone (see figure 7.12a) or both having their own (see figure 7.12b), in many cases participants chose to explore the exhibition together. As participants during the experiments in chapters 5 and 6 followed the set protocol, similar interactions did not occur there. Due to the in-the-wild setting, where participants themselves direct their experience, other uses of the technologies and their combinations become apparent.

Also, when interacting with the interactive tabletop participants who were part of group often did this together. In addition, visitors who did not participate in the study were also part of the interactions within the museum. In some cases both visitors and participants were interacting with the interactive tabletop (see figure 7.13b). Although it was expected that by increasing the interactivity on the interactive tabletop for participants during the 'combined' condition the average interaction time with the display cases would decrease, no significant difference was found. One reason for this might be the limited number of participants using both the smartphone and the interactive tabletop. Longer studies with more participants are needed to gain more insight. However, in a few cases participants did walk back and forth between display cases and the interactive tabletop. Some to entertain their children (see figure 7.13a) others to get more information about the display cases (see figure 7.13b).

(a)

(b)

Figure 7.13: Visitors interacting with the interactive tabletop. Figure (a) shows a mom bringing display cases to the interactive tabletop for her daughter to play with. Figure (b) shows both a participant and a visitor using the interactive tabletop simultaneously.

Overall, the data obtained from the video analysis and recorded smartphone interaction are more reliable. However, they fail to capture participants subjective experiences. On the other hand, the issues with the questionnaires highlight the fact that these might not be suitable to measure visitors' experience in terms of cognitive absorption, system usability and social presence. Their results from these questionnaires might not be as reliable or correct compared to the in-lab studies. Therefore, whether to use an in-lab or an in-the-wild experiments strongly depends on the questions at hand. Some questions might be better to answer in a controlled environment (e.g. those which require questionnaires to get insights in visitors subjective experiences), whereas others might be better for in an in-the-wild setting (e.g. those looking at visitor interaction and collaboration).

# Part III

# Report

# Chapter 8
# Discussion

This thesis took a holistic approach to investigate combinations of technologies in order to create interactive and engaging museum visits while supporting both social and personal experiences. When looking back at the introduction and the Interactive Experience Model defined by Dierking *et al.* the different technologies used in this study fit two of the defined contexts, the social and personal contexts. The application area, museums, their exhibitions, exhibits and artefacts fit the third context, the physical context (see figure 8.1).

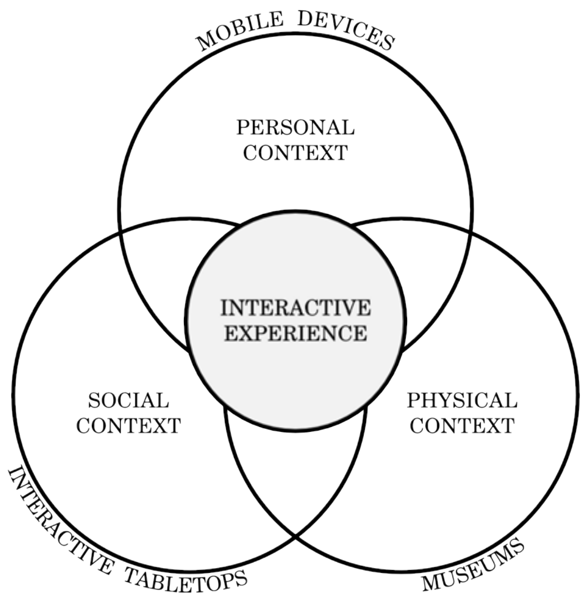



Figure 8.1: Technologies used during the study fit the social and personal contexts of the Interactive Experience Model. The museum with its exhibitions, exhibits and artefacts fit the physical context.

The technologies used during this thesis, mobile and stationary, both have their individual strengths but also limitations. In order to overcome these limitations a new strategy was proposed where combinations of both mobile and stationary technologies could work together in order to provide both social and engaging experiences. The combination of these technologies was tested for different aspects of a museum visit and evaluated from different perspectives. Although according to Dierking *et al.* "the visitor's experience can be thought of as a continually shifting interchange between personal, physical and social contexts" [24] the studies in this thesis suggest that this requires more than just placing the three contexts together.

## 8.1 Evaluating Pervading Exhibits

During the first study combinations of mobile and stationary technologies were tested for perceived usability and affective response. Participants had to organise a small museum exhibition for which they used different combinations of mobile and stationary technologies. After the experiment participants completed questionnaires on affective response and usability. Results of the experiment showed that although new technologies and modalities had a steep learning curve, participants managed to adopt these quickly. Similar results were also found during the final study where participants used a combination of mobile and stationary technologies in an actual museum. Additionally, the first experiment showed that participants preferred interacting with on screen objects through the use of a smartphone. However, the smartphone would have to be an integral part of the interaction as it would otherwise obstruct user interaction.

Having investigated the effects of combining mobile and stationary technologies on single users the next step was to expand both the temporary exhibition and the number of simultaneous visitors to study the effects of combining mobile and stationary technologies on groups. This was done during the second experiment for which findings from the first study were taken into account. Designated places for phone interaction were created and during the study groups of three participants visited a temporary museum exhibition during which they were able to connect their smartphones with museum artefacts and an interactive tabletop through NFC tags. Artefacts could be collected on the phone and during one condition be brought to the interactive tabletop for further interaction. After visiting the exhibitions participants were asked to complete questionnaires on social presence, cognitive absorption and affective response. During their visit participants' position, gaze and interactions were recorded and used for analysis. The results of the experiment show that when participants could continue their interaction on the interactive tabletop, participants spend more time closer together. Moreover, maybe more importantly, this also meant that interaction time with the actual museum artefacts decreased. This suggests that museums should carefully consider the integration of an interactive tabletop into their exhibitions. Although an interactive tabletop could meet the expectations of their visitors, adding one for the sake of interaction will have an effect on the interaction time with the other content of the exhibition. Museums should not lose sight of the fact that for their visitors a museum visit is also an educational experience. Adding an interactive tabletop without considering these implications can therefore defeat their purpose.

In this particular study it is the reciprocity between smartphone and interactive tabletop that make up the visitor's interaction. Whether only adding an interactive tabletop to the exhibition (without the smartphones) would have resulted in similar findings is an interesting question for future work. Previous studies, for example by Hornecker [44] or Hinrichs *et al.* [41], have already shown that interaction duration with interactive tabletops are relatively short. This might however also depend on the complexity of the interactions and available content on the interactive tabletop which in return might result in different levels of visitor engagement.

As a visit to a museum is often also a social event, visitors tend to go with family or friends. In order to also take into account the group composition while using a combination of technologies groups of family or friends took part in a third experiment. The overall setup of the experiment was similar to that of the second experiment, except the fact that only groups of family or friends were allowed to partake in the study. First of all, results from this third study confirmed findings from the second experiment as the interaction time with the actual artefacts was significantly lower when participants were able to continue their interaction on an interactive tabletop. Furthermore, this study provided a deeper understanding of the effects of combining technologies on different types of groups. Where groups of individuals were drawn closer to each other and spent more time together, the opposite was true for groups of family or friends who actually spend more time apart. One reason for this might be that during a visit groups of family or friends stay closer together, whereas groups of individuals might all tend to go their own way. By allowing participants to continue their interaction on the interactive tabletop this draws them around the interactive tabletop. For groups of individuals this actually meant spending more time closer together. However, possibly due to the size of the interactive tabletop, for groups of family or friends this meant spending more time further apart.

One way to test this would be by using a smaller interactive tabletop. However, as this thesis is not looking at differences in visitor experiences between interactive tabletops, this fell outside the scope of this thesis. Although Ryall *et al.* [70] have already studied the effects of tabletop size and found that size did not affect their measurements, they focused on task completion time compared to the distance between participants as in this study. This would be an interesting study for future work and would provide new insights in how the size of an interactive tabletop might influence different types of groups in a museum setting. In this case one would expect that groups of family or friends would not spend more time further apart in a similar setup as during this study, whereas groups of individuals would spend more time even closer. This however, might also give rise to new usability issues.

In addition, the experiment revealed that individual participants became more aware of each others' actions, whereas similar finding were not found for groups of family or friends. This would imply that the potential socialising effects, which have been attributed to interactive tabletops, might actually depend on the composition of the users interacting with them. For individuals interacting with an interactive tabletop might force them to spend more attention to other users, as a result becoming more self-conscious which might limit their engagement. For groups of family or friends, interactions around an interactive tabletop might have a different effect. Compared to groups of individuals they reported lower levels of control during both conditions which might suggest that groups of family or friends rely on each other to figure out how to use the interactive exhibition.

## 8.2 In-Lab vs. In-The-Wild Experiments

As the aim of this work is to explore how combinations of new technologies can contribute to creating interactive and engaging museum visits while supporting both social and personal experiences a final study was held in an in-the-wild setting. This allowed the in-lab studies in this work to be compared with an in-the-wild setting.

Although the overall setup of the experiment was similar to that of the second and third experiment a number of changes were made. First of all, the setup was expanded to accommodate a larger museum collection. In addition, as not every visitor to the museum would be willing to participate in the experiment this had to be taken into account while developing the interactive tabletop application. To make sure these visitors could also use the interactive tabletop it offered some basic functionality. For participants with a smartphone the interactive tabletop allowed them to see more details of the museum collection they had visited. After their visit, participants were asked to complete a short questionnaire on paper.

One of the findings of this study is that compared to in-lab studies, following a set protocol proved to be very difficult during in-the-wild studies as participants often did as they saw fit. The fact that situational, as well as personal, circumstances are difficult to predict makes it hard to design experiments which accounts for all these variables. This is exactly the point researchers of in-the-wild studies are trying to make and suggest that ubiquitous computing technologies should therefore be tested in their 'intended setting'. However, these studies might be costly and difficult to carry out as shown in this experiment. Although Rogers *et al.* [69] have looked at ways to make these in-the-wild experiments worth their while, there still remain usability issues which can not be identified during in-the-wild experiments. Without the tracking as done in the in-lab studies in this work it would have been difficult to indicate that participants spend less time at the museum artefacts when they had access to an interactive tabletop.

A suggestion would be to use these two different experimental paradigms in conjunction. Where in-lab studies might reveal usability issues, in-the-wild studies might reveal situational circumstances that influence how an application, or in this case new technologies, might be used.

# Chapter 9
# Conclusion

This thesis has shown how combinations of technologies can be used for interactive applications. In a number of experiments this work has also shown how these applications are viable options for museums to create engaging exhibitions which can influence personal as well as social experiences. However, how they influence visitor experiences depends on a number of factors. What these findings imply, how they answer the initial research questions, its limitations and what lies ahead will be described in the following sections.

## 9.1 Research Implications

This work has shown that it is worth applying the concept of combining new and existing technologies to meet the increasing expectations of museum visitors. Also in a museum setting "the real power of the concept comes not from any one of these devices – it emerges from the interaction of all of them" [92].

In this work a new strategy was proposed where combinations of technologies worked together in order to create pervading exhibits. These exhibits could present visitors with unique and engaging interactions through the unification of new technologies and allow them to spread the interaction throughout the museum. The strategy was applied in a number of studies which then revealed how it influences visitor behaviour and their experiences.

First of all, one of the studies (see chapter 4) has shown that when combining smartphones with interactive displays, the smartphone should be an integral part of the interaction. Using the smartphone only for part of the interaction impeded further user interaction. Two other studies (see chapters 5 and 6) showed that when visitors where able to continue their interaction with museum artefacts on an interactive tabletop, their experience was strongly influenced by the composition of the users interacting with the tabletop. More specifically, groups of individuals paid more attention to the actions of other users around an interactive tabletop compared to groups of family or friends. For museums this implies that since they attract a diverse group of visitors they will have to keep in mind the effects other visitors can have. In addition, the studies also showed that interaction time with museum artefacts decreased when visitors were able to continue their interaction on an interactive tabletop. Therefore, museums should carefully consider how they incorporate an interactive tabletop in their exhibitions.

Moreover, in order to gain a broader understanding of possible applications using technological combinations and usability issues that might arise from these, museums should conduct both in-lab and in-the-wild studies. Combining results from these studies will provide a broader overview and better understanding of usability issues and situational circumstances.

Finally, this work focussed on museum environments as they are influenced by the introduction of new technologies as well as the rising expectations of their visitors. However, implications of this work are applicable to the wider GLAMs field as aspects of museum visits also exist within galleries, libraries and archives. Most of these work with large collections and the framework developed for the studies carried out in this work allows for these collections to become accessible to visitors' interactions and offer new opportunities for educational as well as entertaining experiences. However, the studies in this work also showed that interaction time with the collection decreased when visitors were able to continue their interaction on an interactive tabletop. GLAMs should therefore carefully consider how their original collection is incorporated with an interactive tabletop. Furthermore, this work has shown that combining a smartphone with an interactive display allows visitors to interact with the collection and carry the interaction throughout the environment onto the interactive displays. However, the smartphone should be an integral part of the interaction as it would otherwise impede further interaction with the interactive display. Taking these implications into account could benefit the wider GLAMs field.

## 9.2 Answering the Research Questions

This thesis makes a timely and novel contribution to the areas of HCI and Digital Heritage by investigating combinations of technologies for creating interactive and engaging museum visits that support both social and personal experiences. To answer the first research question, "How can combinations of new technologies facilitate visitor engagement and interaction in a museum environment?", this work demonstrates the application of pervading exhibits that through the unification of new technologies allow visitors to spread interactions throughout the museum. The third research question, "What are the effects of combining new technologies in a museum environment on user experiences?", was answered by various studies. The studies showed that although new interaction modalities had a steep learning curve, visitors managed to adopt these quickly and confidently used them throughout the rest of their visit. In addition, the studies revealed that when combining smartphones with interactive displays for engaging interactions, the smartphone should be an integral part of the interaction.

By combining smartphones with interactive tabletops this allowed visitors to have private interactions with museum artefacts as well as social interactions around an interactive tabletop. Although this partially answers the second research question, "How can combinations of new technologies facilitate social interaction in a museum environment?", how visitors experienced these interactions strongly depended on the other visitors interacting at the tabletop. This was shown during two studies which tried to answer the fourth research question, "What are the effects of combining new technologies in a museum environment on group experiences?". The studies looked at the combination of technologies as well as different groups. The studies revealed that compared to groups of family or friends, groups of individuals paid more attention to each others' actions around an interactive tabletop. Moreover, the studies also show that interaction time with actual museum artefacts decreased when visitors were able to continue their interaction on an interactive tabletop, suggesting that museums should carefully consider the integration of an interactive tabletop.

Finally, as the aim of this thesis is to feed into the development of future interactive exhibitions for museum it tries to provide a holistic overview from in-lab testing to in-the-wild applications. For this a final study was held at an actual museum environment where combinations of technologies were investigated. Additionally, this also allowed comparing both in-lab and in-the-wild studies. As both paradigms have their advantages and disadvantages this work would suggest to use the two paradigms in conjunction. Where in-lab studies might reveal usability issues, in-the-wild studies might reveal situational circumstances that influence how an application might be used.

## 9.3 Thesis Limitations and Future Work

Although this thesis makes a timely and novel contribution to the areas of HCI and Digital Heritage it does have a number of limitations and there is more work that can be done.

First of all, in this work it is the reciprocity between smartphones and an interactive tabletop that make up the visitor's interaction. The concept of combining technologies can however be much further explored and other technologies or devices can be added and become part of large interconnected networks. The demonstrated system allows new entities to be introduced without changing it. This will open up a whole new range of novel interaction methods to engage visitors and create interactive exhibitions. Other devices, technologies and applications can therefore be an interesting subject for future studies (e.g. allow visitors to control mechanical exhibits, exchange information with terminals or turn exhibitions into educational games). Furthermore, as museums offer many interaction opportunities and have a wide variety of users, this work focused on the combinations of technologies for this particular public institution. However, the demonstrated applications and prototypes are not limited to museums only. Other public institutions such as galleries, libraries and archives could benefit from similar applications and expanding this work to cover more of the GLAMs might therefore be of interest.

A general limitation that applies to all the studies in this work is that it compares a combination of smartphones and interactive tabletop with a smartphone only setup. Therefore, the findings can only be attributed to these specific settings. Other settings are of course possible (e.g. only an interactive tabletop without the smartphone, or neither interactive tabletop nor smartphone). As this work looked at the combination of technologies and tried to keep the amount of depended variables small, other settings fell outside of the scope of this work. However, how the results from these settings differ to the results of the settings used in this work is an interesting question for future work.

Some studies in this work revealed that groups of family or friends were further apart when they were able to use an interactive tabletop. As this could be due to the size of the interactive tabletop comparing the distance between participants with different tabletop sizes would be an interesting study for future work. This would provide new insights in how the size of an interactive tabletop influences the different groups. One would expect that groups of family or friends would not spend more time further apart in a similar setup as during this study, whereas groups of individuals would spend more time even closer. This however, might also give rise to new usability issues as a smaller interactive tabletop also means less interaction space.

The studies looking at effects of combinations of technologies on different types of groups assumed groups of three participants. However, as seen in the final study, group sizes varied among museums visitors (in this particular study ranging from two to six participants). These different group sizes could also be tested in future studies as it is expected that this will have an effect on how visitors experience both the exhibitions and their interactions with an interactive tabletop.

Finally, during all studies within this thesis data was collected for quantitative data analysis. Although this allows for objective analyses which can be easily generalised, it also limits potential findings. For example, using questionnaires restrict participants' responses which could lead to important variables to be overlooked. Using open ended questions or interviews might have exposed these important factors during the studies. Although there is still a wealth of data available which has not been further investigated (e.g. video recordings, follow-up questionnaires), future studies should consider collecting a combination of both quantitative and qualitative data in order to create a more holistic overview of visitor engagement using combinations of mobile and stationary technologies.

# Part IV

# Appendices

# Appendix A:

# A Complex Community of Objects People and Devices

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# THE MUSEUM ENVIRONMENT: A COMPLEX COMMUNITY OF OBJECTS, PEOPLE AND DEVICES


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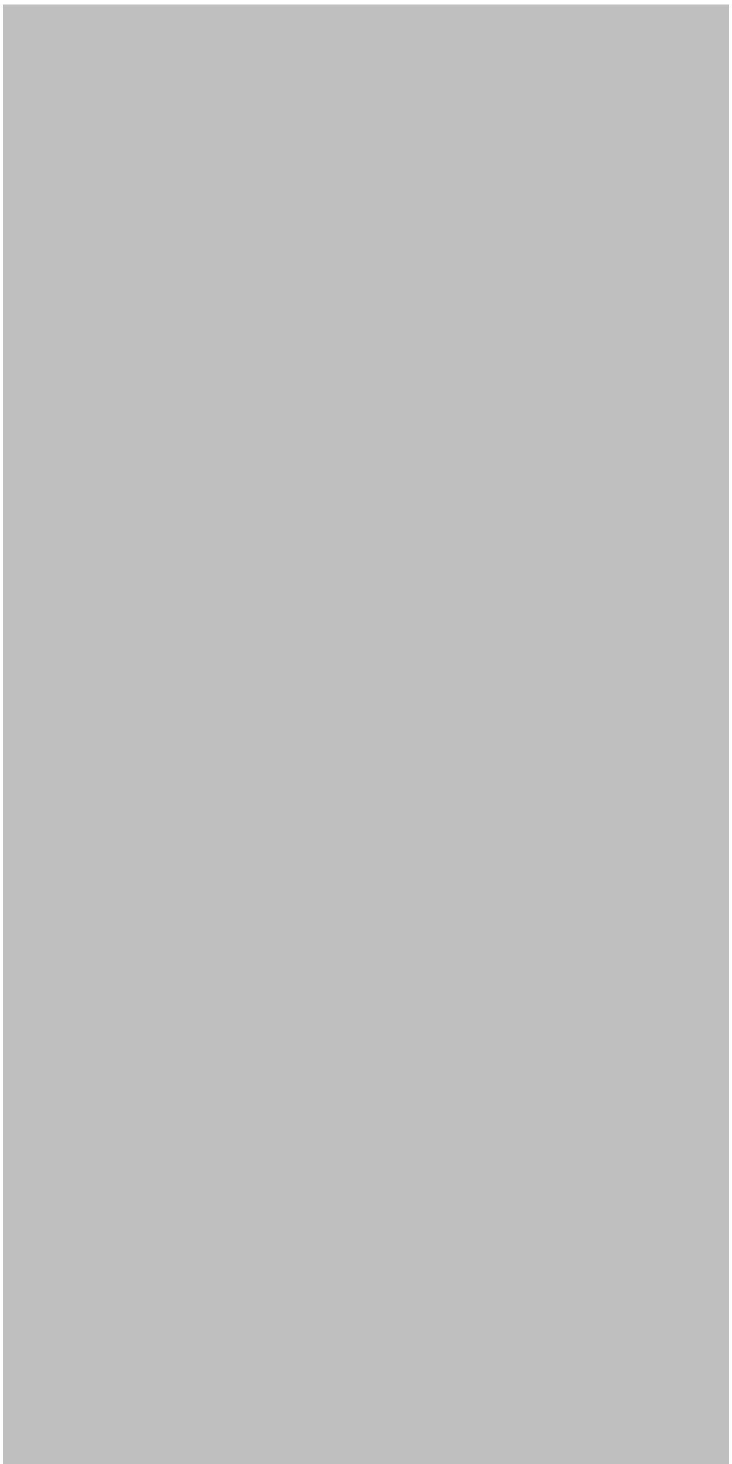
**KEY WORDS:** Interactive exhibits, Mobile technologies, Interactive displays, Museum visitors, Visitor engagement, Interaction framework



**ABSTRACT:**

The beginning of the 21st century is an exciting time for museums in terms of new, engaging and interactive exhibits. Current technological developments offer museums ideal opportunities to meet the increasing expectations of their visitors, many of whom are the younger generation growing up in the digital age. With a multitude of devices and objects as well as people incorporated into an ever-growing network of interconnected systems, new patterns, forms of interactions and social relations will emerge. In order to engage visitors, museums are adopting new technologies which come with many possibilities, but also have their individual challenges and limitations. Museums should start looking at the unification of many such technologies in order to capture visitor attention, engage visitor interaction and facilitate social activities, since the large quantity of digital input and output capabilities of these technologies are hidden potentials. However, unless specifically designed for, many of these capabilities remain hidden and technologies remain oblivious of each other’s features. Making them aware of each other’s capabilities opens the channels for new synergy and engaging experiences for museum visitors. This paper proposes a framework which uniquely identifies a community of people, artefacts and devices within the museum environment and provides the means to discover, and make use of the technological properties of each element, treating them as an interacting ecosystem of complex adaptive systems and networks in physical spaces.



# Appendix B:

# Participant Information Sheet (Experiment 1)

## Study Overview

In this study we are examining the effects of combining new technologies. You will initially be asked to complete a short questionnaire before starting the experiment.

Once you have completed the questionnaire you will be given a smartphone which you will need throughout the rest of the experiment. The experiment itself will be held in the Hall in which you will find a small museum exhibition of four museum artefacts. You are free to interact with these artefacts. In the Hall you will also find four wall-mounted displays that are capable of presenting 3D models of these artefacts. The researcher will provide you with more details before you start and will then lead you to the Hall.

Unfortunately, the exhibition it not finished yet and all four displays in the Hall are blank. It is your task to complete the museum exhibition. You do this by collecting the artefacts, bring them to the correct displays and rotate them to match the requested rotation. Each display will have a picture next to it, telling you which artefacts it needs to show and how it should be rotated.

During the experiment you will use two different methods to rotate the 3D models. Once through the use of the interactive display and once by using the smartphone.

**Interactive display interaction:** Once the artefact is loaded onto the display you can touch the display in order to rotate the 3D model to the required orientation.

**Smartphone interaction:** Once the artefact is loaded onto the display you can touch the smartphone's display in order to rotate the 3D model to the required orientation.

Once you entered the Hall to complete your task, you can leave once you are finished or when you had enough. Afterwards you will then be asked to complete two small questionnaires related to your experience of the visit. After this you will get to repeat your task, only this time using a different interaction method.

All data will always be kept confidential and will only be used for research purposes. You can withdraw from the study at any time by speaking with the researcher, contacting a member of staff, or through contacting Gido Hakvoort from the University of Birmingham at . If you choose to be removed from the study we will ignore any interactions you have had with the artefacts, technologies, and group members during data analysis.

The study should take no longer than 45 minutes to complete.

# Appendix C: Demographics Questionnaire (Experiment 1)

# Participant Questionnaire

Before starting the experiment, I would like to have some demographic information about you. This information will be used only for research purposes and will not be shared with third parties. Your anonymity will be kept in case of scientific publishing. Please answer the questions below correctly with your best knowledge.

* Required

## Demographic information

**Surname; Initial(s)** *

**Age** *

**Mother tongue** *

**Gender** *

- Male
- Female

**Vision** *

- Normal
- Corrected
- Not corrected

**Handedness** *

- Left
- Right
- Both

**Computer usage** *

- Every day
- Every 2-3 days
- Once a week
- More than once a month
- Less than once a month
- Never

**Digital Game experience** *
How often do you play digital games?

- ◯ Every day
- ◯ Every 2-3 days
- ◯ Once a week
- ◯ More than once a month
- ◯ Less than once a month
- ◯ Never

**Virtual 3D Model usage** *
How often do you work with, or use 3D models?

- ◯ Every day
- ◯ Every 2-3 days
- ◯ Once a week
- ◯ More than once a month
- ◯ Less than once a month
- ◯ Never

**Preferred address/number for contact**

# Appendix D:

# Self-Assessment Manikin Questionnaire (Experiment 1)

# Self-Assessment Manikin (SAM)

On the next few pages you will find 3 sets of 5 figures. These sets of figures, called Self-Assessment Manikin (SAM), are used to rate how you felt while using an interaction method to rotate the 3D models. After rotating the 3D models to match your given assignment, you will rate all three figures. For each interaction you will use one complete page on which three kinds of feelings are shown: unhappy vs. happy, calm vs. excited and controlled vs. controlling.

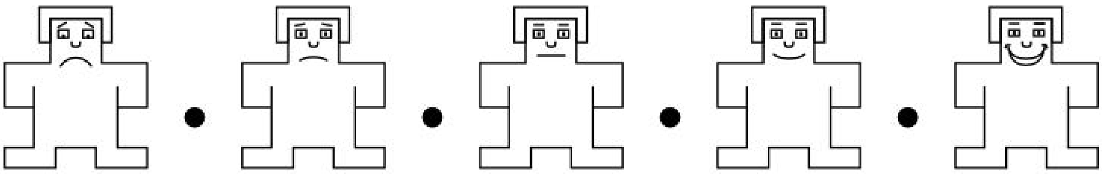
The first SAM scale describes unhappy vs. happy. The figures differ along the scale, ranging from a frown to a smile. At one end of this scale you felt completely unhappy, unsatisfied, bored, melancholic, annoyed, despaired. If you felt completely unhappy while using an interaction method to rotate the 3D model, you can indicate this by circling the number 1. At the other end of this scale you felt completely happy, satisfied, contented, hopeful, pleased. By circling the number 9, you indicate that you felt completely happy. If you felt somewhere in between while using an interaction method, you can circle one of the other numbers.

The second SAM scale describes calm vs. excited. Again the figures differ along the scale. At one end of this scale you felt completely relaxed, calm, unaroused, sluggish, sleepy, dull. You can indicate that you felt completely relaxed by circling the number 1. At the other end of this scale you felt completely aroused, excited, jittery, frenzied, stimulated, wide-awake. If you felt completely aroused while using an interaction method, you can indicate this by circling the number 9. If you circle one of the other numbers you will indicate you felt somewhere in between.

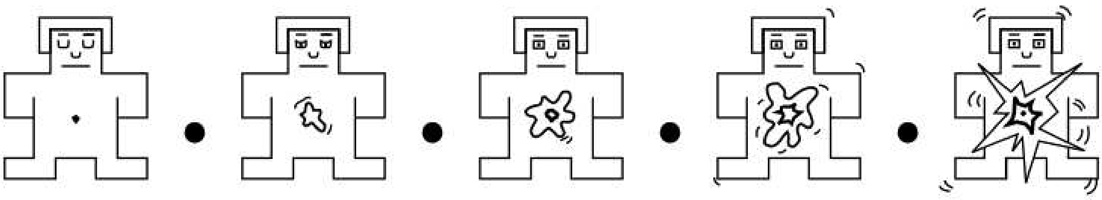
The third and last scale describes controlled vs. controlling. At one end of this scale you felt completely controlled, cared-for, influenced, submissive, awed, guided. If you felt completely controlled, you can indicate this by circling the number 1. At the other end you will again find the opposite feeling, completely in control, controlling, important, influential, dominant, autonomous. If you felt completely in control while using an interaction method to rotate the 3D models, circle the number 9. Circle one of the other number to indicate you felt somewhere in between.

**Important:** Please rate each one of the figures as you actually felt while you used an interaction methods to rotate the 3D models.

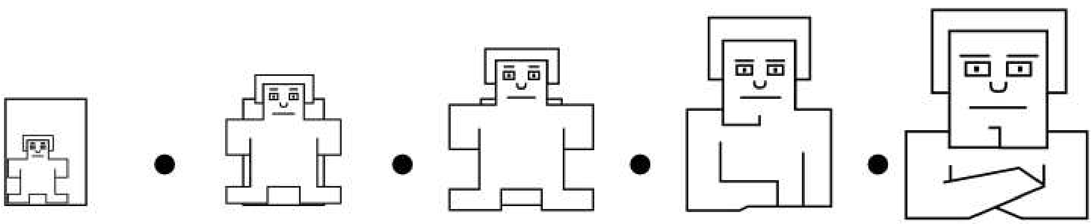
# Describe how you felt while using the current interaction method



1 2 3 4 5 6 7 8 9

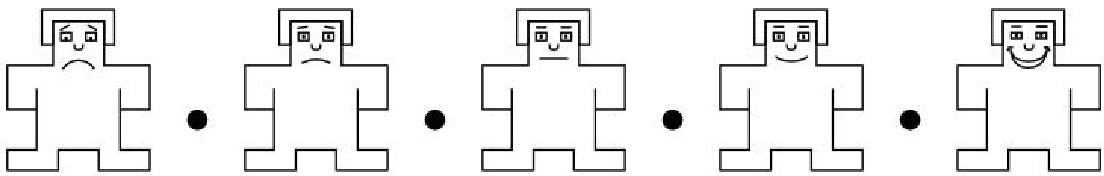


1 2 3 4 5 6 7 8 9

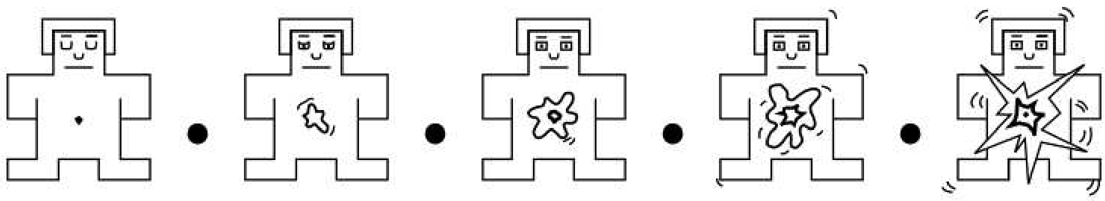


1 2 3 4 5 6 7 8 9

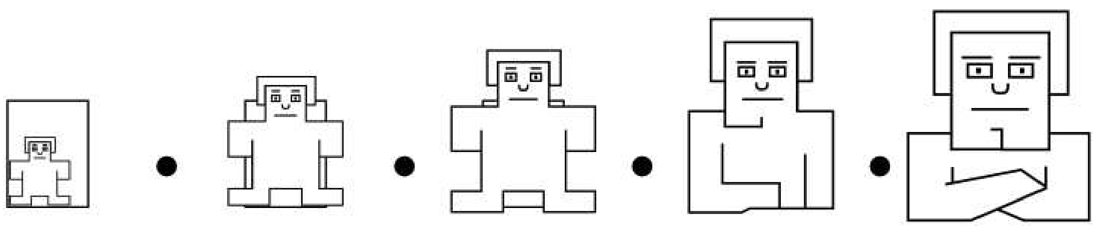
# Describe how you felt while using the current interaction method



1 2 3 4 5 6 7 8 9



1 2 3 4 5 6 7 8 9



1 2 3 4 5 6 7 8 9

# Appendix E:

# System Usability Scale Questionnaire (Experiment 1)

# Usability Questionnaire

Please rate the usability of the system and try to respond to all the items listed below.

* Required

**I think that I would like to use this system frequently** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly Disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly Agree |

**I found the system unnecessarily complex** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly Disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly Agree |

**I thought the system was easy to use** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly Disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly Agree |

**I think that I would need the support of a technical person to be able to use this system** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly Disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly Agree |

**I found the various functions in this system were well integrated** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly Disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly Agree |

**I thought there was too much inconsistency in this system** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly Disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly Agree |

**I would imagine that most people would learn to use this system very quickly** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly Disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly Agree |

**I found the system very cumbersome to use** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly Disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly Agree |

**I felt very confident using the system** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly Disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly Agree |

**I needed to learn a lot of things before I could get going with this system** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly Disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly Agree |

# Appendix F:

# Participant Information Sheet (Experiment 2 and 3)

UNIVERSITY OF BIRMINGHAM

Social Technology - Birmingham, UK

## Study Overview

In this study we are examining the effects of combining new technologies in a museum environment. You will initially be asked to complete a short questionnaire before starting the experiment.

Once you have completed the questionnaire you will be given a smartphone that will allow you to interact with the exhibition. In addition, you will need to wear some glasses that will allow us to track your movements throughout the Hall. Video cameras will also be used in the Hall to record your interactions.

You will be asked to enter the Hall as a visitor to a museum exhibition with two of your friends. In the Hall you will find museum artefacts with which you are free to interact. The researcher will provide you with more details before you start and will then lead you to the Hall. After 15 minutes the researcher will come and fetch you from the museum exhibition. However, if you feel like leaving earlier, please do so and return to the reception area.

After your visit to the museum exhibition the researcher will ask a few questions related to some of the artefacts after which you will be asked to complete a few more questionnaires related to your experience of the visit.

All data and video footage collected will always be kept confidential and will only be used for research purposes. Video footage will only be seen by researchers at the University of Birmingham and will only ever be used to observe how you interacted with the artefacts, technologies and your group members.

You can withdraw from the study at any time by speaking with the researcher, contacting a member of staff, or through contacting Gido Hakvoort from the University of Birmingham at [redacted]. If you choose to be removed from the study we will ignore any interactions you have had with the artefacts, technologies, and group members during data analysis.

The study should take no longer than 45 minutes to complete.

Consent: By taking part in this study you are providing your consent for us to use any video footage and data collected for research purposes.

# Appendix G: Demographics Questionnaire (Experiment 2 and 3)

# Demographics - Basic

Your personal information will not be shared with, or sold to, any third party.

* Required

**Unique ID** *
This will be provided by the experimenter

**Surname; Initial(s)** *

**Email address** *

**Age** *

**Mother tongue** *

**Gender** *

- Male
- Female

**Handedness** *

- Left
- Right
- Both

**Do you own a smartphone?** *

- Yes
- No

# Demographics - Basic

* Required

## Demographics - Smartphone Usage

**What kind of smartphone do you own? ***
(multiple answers possible)

- ☐ Windows
- ☐ Apple
- ☐ Android
- ☐ BlackBerry
- ☐ Other: ____

**Do you have internet on your smartphone? ***

- ○ Yes
- ○ No

**How much time do spend on your smartphone in a day? ***

- ○ Less than 30 minutes
- ○ From 30 minutes to 1 hour
- ○ From 1 to 2 hours
- ○ From 2 to 4 hours
- ○ More than 4 hours

**Please indicate for what you are using your smartphone, and how much time in a day. ***

| | Never | Less than 30 minutes | From 30 minutes to 1 hour | From 1 to 2 hours | More than 2 hours |
|---|---|---|---|---|---|
| Calls | ○ | ○ | ○ | ○ | ○ |
| SMS / MMS | ○ | ○ | ○ | ○ | ○ |
| Internet Browsing | ○ | ○ | ○ | ○ | ○ |
| Email | ○ | ○ | ○ | ○ | ○ |
| Social Media | ○ | ○ | ○ | ○ | ○ |
| Chat | ○ | ○ | ○ | ○ | ○ |
| Listening Music | ○ | ○ | ○ | ○ | ○ |
| Pictures / Videos | ○ | ○ | ○ | ○ | ○ |
| Gaming | ○ | ○ | ○ | ○ | ○ |

# Demographics - Basic

* Required

## Demographics - Computer Usage

**Please indicate your level of computer experience** *

- I don't use computers very often
- I am a frequent computer user
- I am a technical undergraduate
- I am an experience programmer
- I am a graphical designer

**What kind of computer do you use?** *
(multiple answers possible)

- Home Desktop PC
- Work Desktop PC
- Home Laptop
- Work Laptop

**How much time do spend on a computer in a day?** *

- Less than 1 hour
- From 1 to 2 hours
- From 2 to 4 hours
- From 4 to 6 hours
- More than 6 hours

**Please indicate for what you are using a computer, and how much time a day** *

| | Never | Less than 1 hour | From 1 to 2 hours | From 2 to 4 hours | More than 4 hours |
|---|---|---|---|---|---|
| Internet Browsing | | | | | |
| Email | | | | | |
| Social Media | | | | | |
| Chat | | | | | |
| Listening Music | | | | | |
| Pictures / Videos | | | | | |
| Gaming | | | | | |

# Demographics - Basic

* Required

## Demographics - Museum Visits

**Please indicate what kind of public institutions you visited this year** *
(multiple answers possible)

- [ ] Museums
- [ ] Libraries
- [ ] Archives
- [ ] Gallaries

**When was the last time you visited a museum?** *

- ○ Last week
- ○ Last month
- ○ 3 months ago
- ○ 6 months ago
- ○ Last year
- ○ More than a year ago

**When you visit a museum, who do you go with?** *
(multiple answers possible)

- [ ] Friends
- [ ] Family
- [ ] Partner
- [ ] Alone

# Appendix H:
# Social Presence Questionnaire (Experiment 2 and 3)

# Networked Minds Social Presence

* Required

**Unique ID ***
This will be provided by the experimenter

**1) I often felt as if my friends and I were in the Hall together ***

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**2) my friends were often aware of me in the Hall ***

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**3) I often felt as if we were in different places rather than together in the Hall ***

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**4) I hardly noticed my friends in the Hall ***

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**5) I think my friends often felt as if we were in different places rather than together in the Hall ***

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**6) When I was feeling sad my friends also seemed to be down ***

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**7) I was able to communicate my intentions clearly to my friends** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**8) The behavior of my friends was often in direct response to my behavior** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**9) When my friends were feeling sad, I tended to be sad** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**10) my friends paid close attention to me** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**11) I was easily distracted from my friends when other things were going on** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**12) My thoughts were clear to my friends** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**13) My friends' actions were often dependent on my actions** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**14) my friends didn’t notice me in the room** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**15) I tended to ignore my friends** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**16) my friends were easily distracted from me when other things were going on** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**17) I paid close attention to my friends** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**18) When my friend were nervous, I tended to be nervous** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**19) What my friends did often affected what I did** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**20) I think my friends often felt as if we were in the Hall together** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**21) I was sometimes influenced by my friends' moods** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**22) my friends were able to understand what I meant** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**23) When my friends were happy, I tended to be happy** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**24) My friends' thoughts were clear to me** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**25) my friends tended to ignore me** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**26) my friends were sometimes influenced by my moods** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**27) What I did often affected what my friends did** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**28) When I was feeling nervous, my friends also seemed to be nervous** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**29) I was able to understand what my friends meant** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**30) When I was happy, my friends tended to be happy** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**31) My behavior was often in direct response to my friends' behavior** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**32) My actions were often dependent on my friends' actions** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**33) my friends were able to communicate their intentions clearly to me** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**34) I was often aware of my friends in the Hall** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

# Appendix I:
# Cognitive Absorption Questionnaire (Experiment 2 and 3)

# Cognitive Absorption

* Required

**Unique ID** *
This will be provided by the experimenter

**1) If I heard about a new information technology, I would look for ways to experiment with it** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**2) Visiting the exhibition excites my curiosity** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**3) Most times when I go to the exhibition, I end up spending more time that I had planned** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**4) Visiting the exhibition arouses my imagination** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**5) While visiting the exhibition, my attention does not get diverted very easily** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**6) While visiting the exhibition, I am immersed in the task I am performing** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**7) I intend to continue visiting the exhibition in the future** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**8) The exhibition allows me to control my computer interaction** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**9) Visiting the exhibition provides me with a lot of enjoyment** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**10) While visiting the exhibition, I am absorbed in what I am doing** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**11) When visiting the exhibition I am Original** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**12) I enjoy visiting the exhibition** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**13) In general, I am hesitant to try out new information technologies** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**14) I often spend more time visiting the exhibition than I had intended** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**15) Visiting the exhibition bores me** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**16) When visiting the exhibition I am Creative** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**17) I find it easy to get the exhibition to do what I want it to do** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**18) I feel that I have no control over my interactions with the exhibition** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**19) When visiting the exhibition I am Inventive** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**20) When visiting the exhibition I feel in control** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**21) Time appears to go by very quickly when I am visiting the exhibition** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**22) When visiting the exhibition I am Playful** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | | | | | | | | Strongly agree |

**23) Time flies when I am visiting the exhibition** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**24) When visiting the exhibition I am Imaginative** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**25) Interacting with the exhibition makes me curious** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**26) I find the exhibition easy to use** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**27) While visiting the exhibition I am able to block out most other distractions** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**28) When visiting the exhibition, I get distracted by other attentions very easily** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**29) I find the exhibition useful in my university activities** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**30) When visiting the exhibition I am Spontaneous** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | ◯ | Strongly agree |

**31) I like to experiment with new information technologies** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**32) Visiting the exhibition improves my performance in university** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**33) It is easy for me to become skillful at visiting the exhibition** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**34) Visiting the exhibition enhances my productivity** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**35) I expect my use of the exhibition to continue in the future** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**36) Among my peers, I am usually the first to try out new information technologies** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**37) Visiting the exhibition enhances my effectiveness in university** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**38) When visiting the exhibition I am Flexible** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**39) I plan to visit the exhibition in the future** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**40) I feel that I have no control over my interaction with the exhibition** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**41) Sometimes I lose track of time when I am visiting the exhibition** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

**42) I have fun interacting with the exhibition** *

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|
| Strongly disagree | ○ | ○ | ○ | ○ | ○ | ○ | ○ | Strongly agree |

# Appendix J:
# PANAS-X Questionnaire (Experiment 2)

# PANAS-X

* Required

**Unique ID ***
This will be provided by the experimenter

**Positive Affect / Negative affect ***
This scale consists of a number of words and phrases that describe different feelings and emotions. Read each item and then mark the appropriate answer in the space next to that word. Indicate to what extent you feel this way right now. Use the following scale to record your answers:

| | very slightly or not at all | a little | moderately | quite a bit | extremely |
|---|---|---|---|---|---|
| cheerful | | | | | |
| disgusted | | | | | |
| attentive | | | | | |
| bashful | | | | | |
| sluggish | | | | | |
| daring | | | | | |
| surprised | | | | | |
| strong | | | | | |
| scornful | | | | | |
| relaxed | | | | | |
| irritable | | | | | |
| delighted | | | | | |
| inspired | | | | | |
| fearless | | | | | |
| disgusted with self | | | | | |
| sad | | | | | |
| calm | | | | | |
| afraid | | | | | |
| tired | | | | | |
| amazed | | | | | |
| shaky | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| happy | ○ | ○ | ○ | ○ | ○ |
| timid | ○ | ○ | ○ | ○ | ○ |
| alone | ○ | ○ | ○ | ○ | ○ |
| alert | ○ | ○ | ○ | ○ | ○ |
| upset | ○ | ○ | ○ | ○ | ○ |
| angry | ○ | ○ | ○ | ○ | ○ |
| bold | ○ | ○ | ○ | ○ | ○ |
| blue | ○ | ○ | ○ | ○ | ○ |
| shy | ○ | ○ | ○ | ○ | ○ |
| active | ○ | ○ | ○ | ○ | ○ |
| guilty | ○ | ○ | ○ | ○ | ○ |
| joyful | ○ | ○ | ○ | ○ | ○ |
| nervous | ○ | ○ | ○ | ○ | ○ |
| lonely | ○ | ○ | ○ | ○ | ○ |
| sleepy | ○ | ○ | ○ | ○ | ○ |
| excited | ○ | ○ | ○ | ○ | ○ |
| hostile | ○ | ○ | ○ | ○ | ○ |
| proud | ○ | ○ | ○ | ○ | ○ |
| jittery | ○ | ○ | ○ | ○ | ○ |
| lively | ○ | ○ | ○ | ○ | ○ |
| ashamed | ○ | ○ | ○ | ○ | ○ |
| at ease | ○ | ○ | ○ | ○ | ○ |
| scared | ○ | ○ | ○ | ○ | ○ |
| drowsy | ○ | ○ | ○ | ○ | ○ |
| angry at self | ○ | ○ | ○ | ○ | ○ |
| enthusiastic | ○ | ○ | ○ | ○ | ○ |
| downhearted | ○ | ○ | ○ | ○ | ○ |
| sheepish | ○ | ○ | ○ | ○ | ○ |
| distressed | ○ | ○ | ○ | ○ | ○ |
| blameworthy | ○ | ○ | ○ | ○ | ○ |
| determined | ○ | ○ | ○ | ○ | ○ |
| frightened | ○ | ○ | ○ | ○ | ○ |

| | | | | | |
|---|---|---|---|---|---|
| astonished | ○ | ○ | ○ | ○ | ○ |
| interested | ○ | ○ | ○ | ○ | ○ |
| loathing | ○ | ○ | ○ | ○ | ○ |
| confident | ○ | ○ | ○ | ○ | ○ |
| energetic | ○ | ○ | ○ | ○ | ○ |
| concentrating | ○ | ○ | ○ | ○ | ○ |
| dissatisfied with self | ○ | ○ | ○ | ○ | ○ |

# Appendix K:

# Participant Information Sheet (Experiment 4)

UNIVERSITY OF BIRMINGHAM

Birmingham, UK

# Important: Ongoing Experiment!

Welcome to the ‘Stratigraphic Paleontology’ exhibition - please feel free to touch and use the table and interact with the display cases.

In this research study we are examining how visitors interact with objects, technology, and other visitors within a museum environment. If you chose to participate in the study you have been provided a smartphone which allows you to interact with the display cases. Please return the phone when you leave the museum. You will be asked to complete a short questionnaire after your visit.

All data and video footage collected will always be kept confidential and will only be used for research purposes. Video footage will only be seen by researchers at the University of Birmingham and will only ever be used to observe how you interacted with the artefacts, technologies and other visitors.

**Consent:** By visiting the ‘Stratigraphic Paleontology’ exhibition and interacting with the interactive table you are providing your consent to use any video footage and data collected for research purposes.

**Withdrawal:** You can withdraw from this research study at any time by speaking with the researcher, contacting a member of staff, or through contacting Gido Hakvoort from the University of Birmingham at gido.hakvoort@gmail.com. If you choose to be removed from the study we will ignore any interactions you have had with the artefacts, technologies, and group members during data analysis.

**Contact:** Please contact Gido Hakvoort from the University of Birmingham at if you would like further details about this research study.

# Appendix L:

# Lapworth Museum of Geology Questionnaire (Experiment 4)

Welcome to the ‘Stratigraphic Paleontology’ exhibition - if you chose to participate in the study please complete this short questionnaire.

*Although not all questions might apply to you - try to answer them as best as you can.*

| | |
|---|---|
| Age | .... |
| Mother tongue | .... |
| Gender | *Male / Female* |
| Do you own a smartphone? | *Yes / No* |
| How many people are you? | .... |

Please indicate what kind of public institutions you visited this year (multiple answers possible)

*Museums*

*Libraries*

*Archives*

*Galleries*

When was the last time you visited a museum? (please circle one)

*Last week*

*Last month*

*3 months ago*

*6 months ago*

*Last year*

*More than a year ago*

When you visit a museum, who do you go with? (multiple answers possible)

*Friends*

*Family*

*Partner*

*Alone*

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|---|
| I think that I would like to use this system frequently | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I found the system unnecessarily complex | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I thought the system was easy to use | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I think that I would need the support of a technical person to be able to use this system | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I found the various functions in this system were well integrated | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I thought there was too much inconsistency in this system | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I would imagine that most people would learn to use this system very quickly | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I found the system very cumbersome to use | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I felt very confident using the system | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I needed to learn a lot of things before I could get going with this system | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|---|
| Time flies when I am visiting the exhibition | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| While visiting the exhibition, my attention does not get diverted very easily | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I was easily distracted from my partner when other things were going on | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| Interacting with the exhibition provides me with a lot of enjoyment | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I tended to ignore my partner | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I have fun interacting with the exhibition | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| Most times when I visit the exhibition, I end up spending more time that I had planned | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| While visiting the exhibition, I am absorbed in what I am doing | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| My partner was easily distracted from me when other things were going on | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| Visiting the exhibition bores me | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|---|
| I paid close attention to my partner | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| When visiting the exhibition, I get distracted by other attentions very easily | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| Time appears to go by very quickly when I am visiting the exhibition | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| Sometimes I lose track of time when I am visiting the exhibition | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| While visiting the exhibition, I am immersed in the task I am performing | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| My partner tended to ignore me | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I often spend more time visiting the exhibition than I had intended | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| While visiting the exhibition, I am able to block out most other distractions | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| My partner paid close attention to me | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |
| I enjoy visiting the exhibition | Strongly Disagree | O | O | O | O | O | O | O | Strongly Agree |

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